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The Effect on Vegetation and Soil Temperature of Logging Flood-Plain White Spruce

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Abstract

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During winter 1982-83, five silvicultural treatments were applied on Willow Island (near Fairbanks, Alaska): two types of shelterwood cuttings, a clearcutting, a clearcutting with broadcast slash burning, and a thinning. The effects of these treatments on vegetation, soil temperature, and frost depth were followed from 1983 through 1985. In 1984 and 1985, logged plots had significantly higher soil temperatures than did the controls; clearcut and burned sites had the greatest increases. Vegetation composition was profoundly changed on the clearcut and burned units and altered to a lesser extent on the units receiving the other treatments.

Keywords: Alaska, succession, forest communities, site preparation, soil series.

Summary

This study was conducted on Willow Island, a 200-ha island in the Tanana River, near Fairbanks, Alaska. Undisturbed soil and vegetation units were studied before silvicultural treatments were applied. Two soil series were identified and described: (1) Salchaket silt loam, a deep, well-drained alluvial soil lacking continuous permafrost; and (2) Tanana silt loam, which is characterized by impeded drainage resulting from shallow, continuous permafrost. Vegetation consisted mainly of mature white spruce forest, and 13 separate vegetation units were described. By far the most abundant forest communities were open *Picea glauca/Alnus tenuifolia/Hylocomium splendens*, open *Picea glauca/Alnus crispa-A. tenuifolia/Vaccinium vitis-idaea/Hylocomium splendens,* and closed *Picea glauca/Alnus tenuifolia/Hylocomium splendens.* During winter 1982-83, five silvicultural treatments were applied to 79 ha: two types of shelterwood cuttings, a clearcutting, a clearcutting with burning, and a thinning. The effects of these treatments on vegetation and soil temperature and on frost depth were followed from 1983 through 1985.

Clearcutting followed by broadcast slash burning resulted in the most marked changes in vegetation and soil temperature. Many of the predisturbance species dropped out, and the posttreatment vegetation was dominated by invading species (*Populus tremuloides, Ceratadon purpureus*, and *Epilobium angustifolium*) and deep-rooted species (*Equisetum arvense* and *Rosa acicularis*). In one plot where permafrost had been present before clearcutting and burning, soil temperatures at the 10-cm depth were almost twice as high as they were in a nearby undisturbed control; all frost had completely left the soil. Clearcutting without burning diminished the impact on the site.

Many of the plant species originally in the understory survived the logging treatments. Because of remaining insulation provided by the forest floor and vegetative cover, soil temperature increases on clearcut sites (although still appreciable) were less than one-half those measured in areas clearcut and burned. The effects of the shelterwood treatments on the vegetation were minimal. Only three shade-loving species (*Goodyera repens, Calypso bulbosa,* and *Cypripedium passerinum*) dropped out of the stand. Shelterwood cutting resulted in significant increases in soil temperatures that were roughly comparable to those measured in the clearcut areas. The thinning treatments appeared to have the least impact on vegetation, and soil temperatures increased only slightly.

Silvicultural Treatments

Silvicultural treatments were carried out on about 79 ha. Five basic treatments were applied: shelterwood cuttings that left residual stands of two densities, a clearcutting, clearcutting with burning, and a thinning. All logging on the clearcut and shelterwood units was done during winter 1982-83. Because snow cover during logging was fairly deep, logging operations caused very little disturbance to the soil surface (Zasada and others 1987). The units were whole-tree logged; unmerchantable material was piled at the landing. Most of the branch material broke off during skidding and was distributed on the site. There were 2 shelterwood units with about 14-m residual tree spacing (37-62 trees per ha), 5 shelterwood units with 9-m spacing (85-100 trees per ha), 6 clearcuttings, 2 units clearcut and burned, 14 small thinned plots, and 5 unlogged control stands (fig. 1). Treatment units were spread over six forest community types but were predominant in two: open white spruce/mixed alder/cranberry/feathermoss (open *Picea glauca/Alnus/Vaccinium vitis-idaea/Hylocomium splendens*) and open white spruce/thinleaf alder/feathermoss (open *Picea glauca/Alnus/Hylocomium splendens*). Soils in treated areas were mostly two phases of the Salchaket soil series: deep phase and intermittent-frost phase.

Site preparation work, which included broadcast slash burning and mechanical scarification, was done during summer and fall 1983. On two clearcut units (12 and 16), the logging slash was broadcast burned in July 1983. The broadcast burning of the logging slash is described by Zasada and Norum (1986). Slash concentrations at landings were machine piled and burned. Parts of each shelterwood and clearcut unit were then patch scarified, blade scarified, or left unscarified as controls, and forest regeneration plots were established. Each logging unit has at least one set of plots for tree regeneration; larger units have several. Each set includes patch-scarified, blade-scarified, and unscarified areas. Forest regeneration treatments included spot sowing of seed and planting containerized white spruce seedlings.

Methods

The work reported here involved efforts in three distinct areas of study and was carried out from 1981 through 1985. The methods used in the three areas of study will be treated separately.

Soil and Vegetation Reconnaissance and Mapping

During summer 1981, while Willow Island was still completely undisturbed, a reconnaissance study was made of its soils and vegetation. The purpose was to describe the soil and vegetation units and to map their distribution before we began any treatments. Besides the observations made during traverses of the island, detailed soil and vegetation data were collected at about 30 representative locations.

At each location, a soil pit was excavated, and a complete soil profile description was made following procedures outlined in the "Soil Survey Manual" (Soil Survey Staff 1951). At selected locations, soil samples from each horizon were also collected. Measurements of frost depth were taken near each soil pit and randomly between sites by using a steel probe calibrated in centimeters.

At each sampling site the vegetation was also described by making visual estimates of cover for each species within a circular area about 20 m in radius around the soil pit. Tree canopy cover was estimated for a larger area to make that figure more representative. Stand age was approximated from ring counts of increment cores taken at breast height from representative trees at the sampling site.

Soil and vegetation maps were prepared on aerial photographs and then transferred to a planimetric base map. The mapping was done by using the information about each sampling site, comparisons among sites, and inferences made by noting changes in vegetation and landform on the photographs.

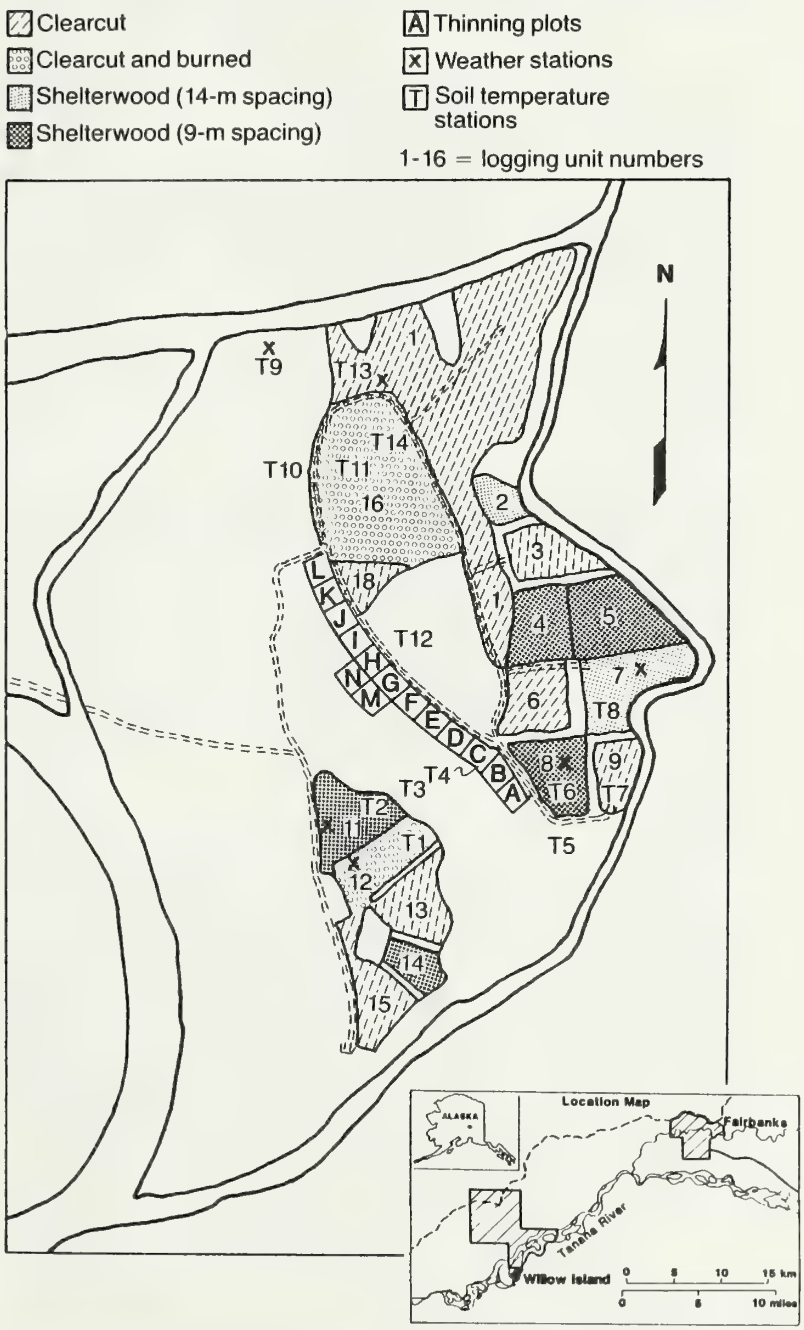

Figure 1—Willow Island with logging units and locations of soil-temperature plots shown.

Monitoring Soil Temperature and Frost

In 1982, before silvicultural treatments were applied, 12 stations were established for monitoring soil temperature and frost. Six plots were in undisturbed, control areas, and six were in areas scheduled for logging (three in shelterwoods and three in clearcuts) (table 1). In 1983 temperature plot 13 was added in a clearcut area, and in 1984 plot 14 was added in a clearcut and burned area. As indicated in figure 1 and table 1, plots were grouped into four clusters, each cluster having one to three silviculturally treated plots and a nearby control plot. Control plots were closely similar to the treated plots, both in vegetation and soil characteristics (table 1). One additional control, plot 9, was near the central climatic station.

During the summers of 1982 through 1985, soil temperatures and frost depths were measured weekly, beginning in late May and extending through mid-September. At each station, soil temperatures were measured at three locations and frost depths at eight locations along a transect. The sites for temperature measurement were permanently marked and were about 2 m apart along the transect. We used two Yellow Springs telethermometer probes, 15 and 90 cm long, to measure soil temperatures at depths of 5, 10, 20, and 50 cm. The probes were inserted vertically and allowed to come to temperature equilibrium with surrounding soil before the values were recorded. Measurements of frost depth were taken along the same transect by using a calibrated steel probe 2 m long. The middle three frost measurements were taken at the marked temperature locations. Frost-depth measurements were also taken at two points 2 m apart at one end of the transect, and at three points at 2-m intervals at the other end of the transect.

Most analyses of soil-temperature data were based on temperature degree-day summations. These soil degree-day accumulations were calculated for both the 10- and the 20-cm depths, with 0 °C as the base, for May 25 to September 15. Analyses of variance were done for these degree-day sums to determine the significance of treatment effects. To facilitate comparison of treatment means, Fischer's protected least significant difference values were calculated. Because of so few replications, all data for control, shelterwood, clearcut, and clearcut and burned plots were pooled for statistical analyses, rather than the analyses being performed on the three separate plot clusters (blocks). In other comparisons, differences between the treated plots and the undisturbed controls were based on the appropriate, paired control and not on pooled data.

Vegetation Monitoring

Twenty permanent vegetation plots were established in each of the 15 logging treatment units, in 5 control units, and in 2 of the 12 thinned units during or before summer 1982. The vegetation on these permanent plots was surveyed using techniques developed by Ohmann and Ream (1971) and Cottam and Curtis (1956), and modified by Foote (1983). The vegetation plots were sampled in 1982 before the logging treatments were begun, in 1983 immediately after treatments were completed, and at the end of the first two growing seasons. Plots in the two burned units were also monitored in 1985. The vegetation growing on these permanently marked plots will be surveyed at intermittent intervals to document the long-term effect of the treatments. These permanent plots are useful for measuring change introduced by the logging, site preparations, and regeneration treatments.

Table 1—Characteristics of logged soil-temperature plots and an associated unlogged control[a]

Treatment and soil-temperature plot number (in parentheses)	Soil unit	Vegetation type
Control (3)	Deep Salchaket	Open *Picea glauca/Alnus/Hylocomium*
Clearcut and burned (1)	Deep Salchaket	Open *Picea glauca/Alnus/Hylocomium*
Shelterwood, 9-m spacing (2)	Shallow Salchaket	Open *Picea glauca/Alnus/Hylocomium*
Control (5)	Salchaket with intermittent frost	Open *Picea glauca/Alnus/Vaccinium/ Hylocomium*
Clearcut (7)	Salchaket with intermittent frost	Open *Picea glauca/Alnus/Vaccinium/ Hylocomium*
Shelterwood, 9-m spacing (6)	Salchaket with intermittent frost	Open *Picea glauca/Alnus/Vaccinium/ Hylocomium*
Shelterwood, 14-m spacing (8)	Salchaket with intermittent frost	Open *Picea glauca/Alnus/Vaccinium/ Hylocomium*
Control (12)	Tanana	Woodland *Picea glauca/Ledum-Vaccinium/feathermoss*
Clearcut and burned (11)	Tanana	Woodland *Picea glauca/Ledum-Vaccinium/feathermoss*
Clearcut (13)[b]	Tanana	Woodland *Picea glauca/Ledum-Vaccinium/*feathermoss
Clearcut and burned (14)[c]	Tanana	Woodland *Picea glauca/Ledum-Vaccinium/*feathermoss
Control (10)	Deep Salchaket	Closed *Picea glauca/Alnus/Hylocomium*
Thinned (4)	Deep Salchaket	Closed *Picea glauca/Alnus/ Hylocomium*
Control (9)[d]	Deep Salchaket	Open *Picea glauca/Alnus/ Hylocomium*

[a] Location of the plots is shown in figure 1. Soil temperature and frost depth were measured from 1982 (before logging) through 1985 except plots 13 and 14.
[b] Plot added 1983.
[c] Plot added 1984.
[d] Not paired with any logged plot. Installed as a supplement to the main climatic station on Willow Island.

Results and Discussion

Soils of Willow Island

The alluvial soils of Willow Island are young and generally show little profile development. They formed in highly variable water-laid deposits of sand and silt. About 90 percent of the island has soils classified as belonging to the Salchaket soil series (Typic Cryofluvents). Salchaket soils are well drained and develop in alluvial deposits on generally level terraces and flood plains. Soil profiles typically exhibit several periods of alluvial deposition separated by organic horizons (buried forest floor layers). Three phases of the Salchaket soil were recognized and described: a deep phase, a shallow phase, and a phase with intermittent frost.

The deep phase of the Salchaket soil occupies at least two-thirds of the total area. These are soils with fine materials (sand and silt) that are at least 75 cm deep over water-worn gravels. In the shallow phase of the Salchaket, gravels are encountered within the top 25-75 cm. Deep Salchaket soils are characterized by forest floor layers varying from very thin (1-3 cm) to moderately thick (14-16 cm). The humus layer ranges from absent to 3 cm thick. Silt from recent floods is often intermixed with the forest floor material. The mineral soil is comprised of silt and sand-sized particles, and texture tends to become coarser with depth. A typical profile may have 20-40 cm of silt loam over horizons of very fine sandy loam that lie over layers of fine to medium sands. Roots are abundant near the surface, particularly in the organic layers, but decrease rapidly with depth.

The following is a generalized description of a profile typical of a deep Salchaket soil on Willow Island: 4-0 cm, recently deposited litter and feathermoss remains; 0-4 cm, grayish brown (10 YR 5/2)[1] silt loam, weak fine subangular blocky structure, very friable, roots abundant; 4-7 cm, very dark grayish brown (10 YR 3/2) organic material (buried forest floor layer), roots abundant; 7-19 cm, brown (10 YR 5/3) with mottles of light gray (10 YR 6/1) and yellowish brown (10 YR 5/6) silt loam, weak fine platy structure, friable, roots abundant; 19-24 cm, brown (10 YR 5/3) with scattered mottles of light gray (10 YR 6/1) silt loam with common lenses of organic material, weak medium subangular blocky structure, friable, roots abundant; 24-35 cm, brown (10 YR 5/3) with scattered mottles of light gray (10 YR 6/1) and yellowish brown (10 YR 5/6), fine sandy loam, very weak subangular blocky structure, very friable, roots common; 35-61 cm, grayish brown (10 YR 5/2) fine sand, single-grained, loose, few roots; 61-80 cm, grayish brown (10 YR 5/2) medium sand, single-grained, loose, scattered roots; and 80-100+ cm, grayish brown (2.5 Y 5/2) sands and water-worn gravels, roots very scattered.

The intermittent-frost phase of the Salchaket soil is similar to the deep phase in horizon characteristics except that lenses of ice are observed in the subsurface layers, usually at depths of 40-60 cm. Most often the layers of frozen soil are discontinuous and do not appear to occur in any pattern. Reiger and others (1963) also observed these frozen lenses in Salchaket soils and described them as "thin silty lenses that...stay frozen...long after the sandy strata have thawed." The ice content of the frozen layers is often low, and the layers can be punctured by a shovel or probe. By late summer, much of the frost has retreated to deeper layers or has completely left the profile.

The intermittent-frost phase of the Salchaket soil occupies about one-fifth of the total area of Willow Island and is restricted to the eastern side. These soils are characterized by forest floors 5-23 cm thick. Silt is commonly intermixed with the organic materials. At least a thin humus layer is generally present above the mineral soil. As in the deep phase of the Salchaket, textures of the surface mineral soil tend to be silt loams, with the soil becoming more coarse textured (sandier) with depth. A

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[1] Munsell color notation for moist soil.

substratum of rounded gravels occurs at depths greater than 1 m. Roots are abundant in the forest floor and common to about the 10-cm depth in the mineral soil. Roots are also abundant in the buried organic layers common in these soils.

The shallow phase of the Salchaket soil is uncommon and occupies only 1-2 percent of the area in the interior of the island. The forest floor layer in these soils is thin to lacking. The mineral soil is generally a fine sand, and water-worn gravels are found at depths of 25-75 cm.

The Tanana soil series includes soils characterized by a shallow active layer and a continuous permafrost layer. They are classified as Pergelic Cryaquepts. Tanana soils occupy about 10 percent of the area and are located on a midisland terrace surrounded by abandoned sloughs. This terrace is farthest from the current river channel and presumably is the oldest landform on the island. Tanana soils are poorly drained and have silt loam surface textures that grade, with depth, into more coarsely textured soils. The forest floor is generally well developed and is 15-25 cm thick. Depth to permafrost is generally in the 50- to 70-cm range at the end of the growing season. Impeded drainage due to the permafrost table causes the soils under undisturbed vegetation to be wet throughout the growing season. Roots are abundant only in the forest floor and the top horizon of the mineral soil; poor soil drainage restricts deeper penetration.

The following is a generalized description of a soil typical of the Tanana series on Willow Island: 15-0 cm, recently deposited litter and partially decomposed moss remains; 0-5 cm, very dark grayish brown (10 YR 3/2) silt loam, weak granular structure, very friable, roots abundant; 5-10 cm, grayish brown (10 YR 5/2) with mottles of dark yellowish brown (10 YR 4/4) and brown (7.5 YR 4/4) fine sandy loam, weak fine subangular blocky structure, friable, roots scattered; 10-19 cm, dark grayish brown (2.5 Y 4/2) with scattered mottles of dark yellowish brown (10 YR 4/4) and gray (10 YR 5/1) loamy fine sand, weak very fine subangular blocky structure, friable, roots scattered; 19-37 cm, dark grayish brown (2.5 Y 4/2) with scattered mottles of yellowish brown (10 YR 5/4) loamy fine sand, weak fine subangular blocky structure, friable, roots very scattered; and 37 cm and deeper, ice-rich permafrost.

Vegetation of Willow Island

Thirteen vegetation mapping units were established based on reconnaissance plot data, additional field examination, and aerial photo interpretation. These mapping units are, for the most part, forest communities conforming to standards described in Viereck and others (1986). According to this classification, the canopy coverage of the tree layer is broken down as follows: woodland with 10-25 percent tree cover, open forest with 25-60 percent tree cover, and closed forest with 60-100 percent tree cover. The 13 communities mapped on Willow Island are described below, roughly in descending order of their abundance.

Open *Picea glauca/Alnus tenuifolia/Hylocomium splendens* (open white spruce/thinleaf alder/feathermoss)--This forest community occupies the largest area on Willow Island, about one-third of the island. It occurs primarily on the western half of the island on deep Salchaket soils. Tree overstory cover ranges from about 30 to 60 percent and is primarily white spruce. Balsam poplar often occurs as a very minor component in the overstory, and dead standing and down trees are commonly scattered throughout the stand. White spruce vary from 15 to 35 cm in diameter at breast height (d.b.h.) and range from 110 to 150 years old.

Alder cover is highly variable, ranging from about 10 to 80 percent. *Alnus tenuifolia* is by far the most common species, but *A. crispa* also occurs. Other tall shrub species include *Rosa acicularis* and *Viburnum edule* (Michx.) Raf. *Linnaea borealis* L. is the dominant low shrub; however, *Vaccinium vitis-idaea* is sometimes present in small quantities. *Geocaulon lividum* (Richards.) Fern. is the dominant herb (2-15 percent cover). Other common herbs are *Pyrola asarifolia* Michx. and *P. secunda* L. Herbs occurring in smaller quantities include *Carex* spp., *Hedysarum alpinum* L. subsp. *americanum* (Michx.) Fedtsch., *Equisetum arvense, E. scirpoides* Michx., and *Goodyera repens* (L.) R. Br. var. *ophioides* Fern. The moss layer is highly variable with the cover ranging from 15 to 95 percent. The dominant moss species is *Hylocomium splendens* (Hedw.) B.S.G., though *Pleurozium schreberi* (Brid.) Mitt., *Drepanocladus* sp., and *Eurhynchium* sp. are also common. Lichens, mostly *Peltigera* spp., are present but uncommon.

This community type was one of the major types used in this study and is represented by silvicultural treatment units 11 to 15 and soil temperature stations T1 through T3 (fig. 1).

Open *Picea glauca/Alnus crispa-A. tenuifolia/Vaccinium vitis-idaea/Hylocomium splendens* (open white spruce/mixed alder/lingonberry/feathermoss)--This forest community occupies about 25 percent of the total area and occurs exclusively on the northeast portion of island. It is associated with colder, generally wetter soils--the intermittent frost phase of the Salchaket and the Tanana soil series. The forest canopy, primarily white spruce, ranges from 30 to 50 percent in cover. The only other tree species is paper birch, which occurs in varying amounts. Average d.b.h. of white spruce is 20-40 cm, and ages range from 130 to over 350 years.

Alnus crispa and *A. tenuifolia* are the dominant tall shrubs with cover of 10-80 percent. Other commonly occurring shrubs include *Rosa acicularis* and *Viburnum edule*. The dominant species in the low shrub-herb layer is *Vaccinium vitis-idaea* (20-50 percent cover). *Linnaea borealis, Equisetum arvense, Cornus canadensis* L., and *Geocaulon lividum* are always present. Other herbs frequently occurring in smaller quantities include *E. scirpoides, Pyrola asarifolia, Calamagrostis canadensis* (Michx.) Beauv., *Hedysarum alpinum, Mertensia paniculata* (Ait.) G. Don, *P. secunda, Moneses uniflora* (L.) Gray, *Goodyera repens*, and *Carex* spp. This community has a luxuriant moss cover, primarily of *Hylocomium splendens*. Other moss species include *Pleurozium schreberi, Rhytidiadelphus triquetrus* (Hedw.) Warnst., *Dicranum fuscescens* Turn., *Eurhynchium* sp., *Drepanocladus* sp., and leafy liverworts, primarily *Ptilidium ciliare* (L.) Nees.

This type differs from the previously described open white spruce type primarily by being much older, by having *Alnus crispa* as well as *A. tenuifolia* in the shrub understory, and by having the colder wetter soils often associated with permafrost. Silvicultural treatment units 2 through 9 and soil temperature units T5 and T9 are in this type.

Closed *Picea glauca/Alnus tenuifolia/Hylocomium splendens* (closed white spruce/thinleaf alder/feathermoss)--This forest community occurs in several locations and occupies about 25 percent of the total area of the island. The associated soil is generally the deep phase of the Salchaket series. The overstory cover ranges from 55 to 70 percent and is mostly white spruce with minor amounts of balsam poplar and paper birch (*Betula papyrifera* Marsh.). Some scattered tamarack (*Larix laricina* (Du Roi) K. Koch) and black spruce are also present. White spruce trees are about 120-150 years old and 15-20 cm d.b.h.

Cover provided by alder, primarily *Alnus tenuifolia*, is highly variable and ranges from about 5 to 75 percent. As in the more open community described above, other, less abundant tall shrub species include *Rosa acicularis* and *Viburnum edule*. The low shrub-herb layer is generally poorly developed and made up of *Carex* spp., *Geocaulon lividum, Pyrola asarifolia, P. secunda, Linnaea borealis, Equisetum arvense*, and *Calamagrostis canadensis. Vaccinium vitis-idaea* may be present but provides less cover than does *L. borealis*. The moss layer is usually well developed (averaging 60-45 percent cover) and is mostly *Hylocomium splendens*, though *Dicranum* sp., *Drepanocladus* sp., and *Eurhynchium* sp. are present. The lichen layer is sparse and primarily composed of *Peltigera* lichens. This type differs from the open *Picea glauca/Alnus/Hylocomium splendens* type only in having a slightly more closed canopy, less *R. acicularis* and *L. borealis*, and fewer herbs.

A series of small thinning plots was established in this type (units A-L), and two soil temperature stations (T4 and a control T10) were used to look at the effects on soil temperatures of one of the thinning treatments.

Open *Picea glauca/Alnus tenuifolia/Calamagrostis-Vaccinium vitis-idaea* (open white spruce/thinleaf alder/bluestem-lingonberry)--This community is characterized by an open stand of predominantly young white spruce. It occupies about 5 percent of the area of Willow Island and is centered in the western portion of the island where selective logging was done about 50 years ago. Associated soils are mostly deep Salchaket and Tanana. White spruce, 30-50 years old and 10 cm d.b.h., is the major tree component. Paper birch is generally present and may contribute up to one-third of the total canopy. Tree canopy coverage ranges from 30 to 60 percent.

Alder is the dominant shrub (30-45 percent cover). Other common tall shrubs are *Salix* spp., *Rosa acicularis, Viburnum edule*, and *Ledum groenlandicum* Oeder. The herb and low shrub layer is well developed with an average cover of about 70 percent. The dominant species are *Calamagrostis canadensis, Vaccinium vitis-idaea*, and *Equisetum arvense*. Other herbs present in smaller quantities are *Linnaea borealis, Geocaulon lividum, Carex* spp., *Cornus canadensis*, and *Epilobium angustifolium* L. The moss layer is open (15-30 percent cover) and predominantly *Hylocomium splendens*.

Open *Picea glauca/Alnus tenuifolia* (open white spruce/thinleaf alder)--This community is open stands of young white spruce with poorly developed herb layers. It is found on 5 percent of the area and on deep Salchaket soils on the western side of the island. Spruce cover ranges from 25 to 60 percent and is made up of small (15 cm d.b.h.) and young (40 years) trees. Scattered older balsam poplar are sometimes encountered.

The most common tall shrubs (10-50 percent cover) are *Alnus tenuifolia, Salix alaxensis* (Anderss.) Cov., and *Rosa acicularis*. The sparse herb layer is dominated by *Geocaulon lividum, Calamagrostis canadensis*, and *Equisetum arvense*. Other common species are *Pyrola asarifolia*. Mosses and lichens are not abundant in this community.

Closed tall *Salix* (closed tall willow)--This dense willow community occurs on the flood plain immediately adjacent to the river along all margins of the island. The width of this band varies, but in most locations it is only a few meters across. The community makes up about 2.5 percent of the island's area. The dense shrub cover is primarily *Salix* spp., but some *Alnus tenuifolia* may be present. The herb layer is scattered and mainly *Equisetum* spp.

Woodland *Picea glauca/Ledum groenlandicum-Vaccinium vitis-idaea*/feathermoss (woodland white spruce/Labrador tea-lingonberry/feathermoss)--This community occurs on the oldest land surface in the center of the island on the Tanana soil characterized by shallow permafrost. It occupies about 2 percent of the total area. The tree overstory is open and usually provides only 15-20 percent cover. Although white spruce is dominant, black spruce is common (up to one-third of the stand); paper birch also occurs. Both white spruce and black spruce have an average d.b.h. of 20 cm. White spruce is about 200 years old, and the black spruce is about 130 years old. The many remains of large trees on the ground suggest that present stands may be the second or even third generation.

The tall shrub layer is sparse and mostly *Salix* spp. and *Rosa acicularis*. Low shrubs are abundant, however, with *Ledum groenlandicum* and *Vaccinium vitis-idaea* being dominant. *Empetrum nigrum* L., *Linnaea borealis*, and *V. uliginosum* L. also occur in smaller quantities. Common herbs are *Equisetum arvense, Geocaulon lividum*, and *Cornus canadensis*, though *Calamagrostis canadensis, E. scirpoides, Lycopodium annotinum* L., and *Pyrola secunda* also occur. Moss cover is well developed and averages 60-70 percent. Dominant species are *Hylocomium splendens* and *Pleurozium schreberi.* Minor components are *Dicranum fuscescens, Sphagnum* spp., *Drepanocladus* sp., and leafy liverworts, primarily *Ptilidium ciliare.* Lichen cover averages 15-35 percent and is predominantly *Peltigera aphthosa* (L.) Willd., though *P. canina* (L.) Willd., *Cetraria islandica* (L.) Ach., and several *Cladonia* species (*C. amauocraea* (Flörke) Schaer., *C. gracilis* (L.) Willd., *C. rangiferina* (L.) Web., and *C. sylvatica* (L.) Hoffm.) occur.

This woodland type was represented in this study by a large clearcutting (units 1 and 16), much of which was also burned (unit 16) and by soil temperature units T11 through T14 (fig. 1).

Closed *Populus balsamifera/Alnus tenuifolia/Equisetum* (closed balsam poplar/thinleaf alder/horsetail)--This forest community is of limited extent and is confined to the western portion of the island on deep Salchaket soils. The stands are fairly dense with an average canopy coverage of about 75 percent. White spruce is also generally present in the understory. Balsam poplar age is about 60-80 years. The tall shrub layer is dominated by *Alnus tenuifolia* and has smaller quantities of *Salix novae-angliae* Anderss., *Rosa acicularis*, and *Viburnum edule.* The herb layer is dominated by *Equisetum arvense; Geocaulon lividum* is also common. Species present in smaller quantities include *Hedysarum alpinum, Cornus canadensis, Calamagrostis canadensis, Epilobium angustifolium, Linnaea borealis,* and *Pyrola asarifolia.* The ground cover is mostly leaf litter with only traces of feathermoss.

Closed *Picea glauca/Equisetum/Hylocomium* (closed white spruce/horsetail/feathermoss)--These stands are mostly small white spruce, which are closely spaced and occur near the eastern margin of the island (less than 1 percent of the total area). The type occurs on the intermittent frost phase of the Salchaket soil. The trees are 10-20 cm d.b.h. and their average age is about 130 years. Alder is absent from this community, unlike most of the island communities, and the only tall shrubs are scattered *Rosa acicularis and Viburnum edule.* The herb layer is marked by a luxuriant cover of *Equisetum arvense* (up to 75 percent cover). Other herbs present in small amounts include *Vaccinium vitis-idaea, Cornus canadensis, Linnaea borealis, Geocaulon lividum, Mertensia paniculata,* and *Pyrola asarifolia.* Mosses are dense and luxuriant (90 percent cover). The dominant species is *Hylocomium splendens;* however, *Pleurozium schreberi, Rhytidiadelphus triquetrus,* and *Dicranum fuscescens* are also present.

Woodland *Picea glauca/Alnus tenuifolia/Arctostaphylos uva-ursi*/lichen (woodland white spruce/thinleaf alder/bearberry/lichen)--Although the distribution of this community is limited, it is unlike any other on the island. It is located in the middle of the island on the shallow phase of the Salchaket soil. The white spruce overstory is very open, averaging perhaps 25 percent cover. The tall shrub layer is also quite open and consists of *Alnus tenuifolia* and *Salix* spp. The herb and low shrub layer is sparse and is dominated by patches of *Arctostaphylos uva-ursi* (L.) Spreng. *Hedysarum alpinum* is also present in small amounts. Mosses are scattered and mostly *Polytrichum* spp. Lichens provide the most abundant cover in this unit. Lichens identified are *Stereocaulon* spp., *Cladonia gracilis, C. alpestris* (L). Rabenh., and *C. sylvatica*.

Abandoned sloughs--Abandoned water channels are abundant on the island but have not been adequately described. Some are only slightly noticeable as depressions, but others are wide and deep. White spruce occurs in a few of the sloughs, but alder is more common. Sweetgale (*Myrica gale* L.) is an occasional low shrub. In most of the sloughs, herbaceous species provide most of the cover. Grasses, sedges, iris (*Iris setosa* Pall.), and some composites make up most of the cover. When the river stage is high, most sloughs become temporarily flooded.

Closed *Picea glauca/Alnus crispa-A. tenuifolia/Vaccinium vitis-idaea/Hylocomium splendens* (closed white spruce/mixed alder/lingonberry/feathermoss)--This type differs from the open *Picea glauca/Alnus crispa-A. tenuifolia/Vaccinium vitis-idaea/Hylocomium splendens* type previously described in that the tree canopy is more closed; the alder has a little less cover; and *Vaccinium vitis-idaea, Linnaea borealis,* and *Hylocomium splendens* tend to have greater cover.

Open *Picea glauca/Hylocomium splendens* (open white spruce/feathermoss)--Stands of this type occasionally occur near sloughs or along the edge of the island. Tree size and age vary. In some stands, they are 20-34 cm d.b.h. and 150-210 years old; in other stands, the d.b.h. is 6-27 cm and the age is about 115 years. Alder has low cover. The shrub layers, both tall and low, and the herb layer are poorly developed, each covering less than 15 percent of the forest floor. *Rosa acicularis* and *Viburnum edule* dominate the tall shrub layer; *Linnaea borealis, Geocaulon lividum,* and *Equisetum arvense* are most abundant in the low shrub and herb layer. The moss layer, which is well developed, is dominated by *Hylocomium splendens* and *Rhytidiadelphus triquetrus*. Lichens, primarily *Peltigera* and a few *Cladonia* growing on mineral soil, occur but are not common.

Effects of Logging Treatments on Soil Temperature

We had the unusual opportunity to compare soil temperatures on control plots and treated plots before treatments were applied in 1983. We used soil degree-days for the entire measurement period as the basis of comparison; correlation of temperatures at a depth of 10 cm between the control plots and plots destined to have treatments was quite good (table 2). With the exception of plot 8, agreement was within $\pm$ 15 percent in 1982 before treatment. Soil temperatures at plot 8, even before treatment, were considerably warmer than those in the control plot. At a depth of 20 cm, differences in soil temperature in 1982 between the control and plots to be treated were greater (table 3). Once again, by far the largest difference was between the control and plot 8, where it was almost 60 percent. The reason for this difference between temperature variation at 10 and 20 cm is obscure; temperature uniformity usually increases with soil depth.

Table 2—Soil degree-day values at the 10-cm depth for the 16-week growing season (last week in May to mid-September) in 1982 (before logging) and the first 3 years after logging (1983-85) by logging treatment, soil-temperature plot, and site preparation[a]

Logging treatment soil-temperature and plot number	1982				1983				1984				1985			
	Control plot	Treated plot	Treated minus control	Difference	Control plot	Treated plot	Treated minus control	Difference	Control plot	Treated plot	Treated minus control	Difference	Control plot	Treated plot	Treated minus control	Difference
				Percent				*Percent*				*Percent*				*Percent*
Shelterwood:																
2, undisturbed	937.3	797.3	-140.0	-14.9	879.8	946.3	66.5	7.6	688.1	805.7	117.6	17.1	767.2	868.7	101.5	13.2
2, scarified									688.1	912.8	224.7	32.6	767.2	945.0	177.8	23.2
2, disturbed									688.1	861.7	173.6	25.2	767.2	926.1	158.9	20.7
6, undisturbed	853.3	905.7	52.4	6.1	795.9	820.6	24.7	3.1	683.2	860.3	177.1	25.9	710.5	967.4	256.9	36.2
6, scarified									683.2	884.8	201.6	29.5	710.5	978.6	268.1	37.7
6, disturbed									683.2	753.9	70.7	10.3	710.5	918.4	207.9	29.3
8	853.3	1177.4	324.1	38.0	795.9	1116.5	320.6	40.3	683.2	985.6	302.4	44.2	710.5	1051.4	340.9	48.0
Mean				9.7				17.0				26.4				29.8
Clearcut:																
7	853.3	908.6	55.3	6.5	795.9	937.3	141.4	17.8	683.2	826.7	143.5	11.9	710.5	915.6	205.1	28.9
13					1011.5	752.5	259.0	-25.6	733.6	816.2	82.6	11.3	660.1	853.3	193.2	29.3
Mean				6.5				-3.9				11.6				29.1
Clearcut and burned:																
1	937.3	935.9	-1.4	0	879.8	1106.7	226.9	25.8	688.1	1086.4	397.9	57.8	767.2	1111.6	344.4	44.9
11	882.7	760.2	-122.5	-13.9	1011.5	1030.4	18.9	1.9	733.6	1159.9	426.3	58.1	660.1	1247.4	587.3	89.0
14									733.6	946.4	212.8	29.0	660.1	940.8	280.7	42.5
Mean				-7.0				13.8				48.3			58.8	
Thinned, 4	876.4	796.6	-79.8	-9.1	853.3	761.6	-91.7	-10.7	693.0	587.3	-105.7	-15.2	657.3	736.4	79.1	12.0

[a] Values for logged plots are compared to those for the undisturbed controls.

Table 3—Soil degree-day values at the 20-cm depth for the 16-week growing season (last week in May to mid-September) in 1982 (before logging) and the first 3 years after logging (1983-85) by logging treatment, soil-temperature plot, and site preparation[a]

Logging treatment soil-temperature and plot number	1982 Control plot	1982 Treated plot	1982 Treated minus control	1982 Difference	1983 Control plot	1983 Treated plot	1983 Treated minus control	1983 Difference	1984 Control plot	1984 Treated plot	1984 Treated minus control	1984 Difference	1985 Control plot	1985 Treated plot	1985 Treated minus control	1985 Difference
				Percent				*Percent*				*Percent*				*Percent*
Shelterwood:																
2, undisturbed	637.0	491.4	-145.6	-22.9	632.8	626.3	-6.5	-1.0	457.1	611.1	154.0	33.7	572.6	746.2	173.6	30.3
2, scarified									457.1	717.5	260.4	57.0	572.6	858.2	285.6	49.9
2, disturbed									457.1	642.6	185.5	40.6	572.6	786.8	214.2	37.4
6, undisturbed	519.4	582.4	63.0	12.1	562.1	534.1	-28.0	-5.0	456.4	616.0	159.6	35.0	496.3	769.3	273.0	55.0
6, scarified									456.4	784.0	327.6	71.8	496.3	882.7	386.4	77.9
6, disturbed									456.4	585.2	128.8	28.2	496.3	815.5	319.2	64.3
8	519.4	823.2	303.8	58.5	562.1	936.6	374.5	66.6	456.4	859.6	403.2	88.3	496.3	958.3	462.0	93.1
Mean				15.9				20.2				50.7				58.3
Clearcut:																
7	519.4	548.1	28.7	5.5	562.1	723.8	161.7	28.8	456.4	660.1	203.7	44.6	496.3	804.3	308.0	62.1
13					404.6	427.7	23.1	5.7	266.7	473.9	207.2	77.7	284.2	522.2	238.0	83.7
Mean				5.5				17.2				61.2				72.9
Clearcut and burned:																
1	637.0	716.1	79.1	12.4	632.8	893.2	260.4	41.2	457.1	987.0	529.9	115.9	572.6	1068.2	495.6	86.6
11	436.8	287.0	-149.8	-34.3	404.6	555.8	151.2	37.4	266.7	938.0	671.3	251.7	284.2	1070.3	786.1	276.6
14									266.7	497.7	231.0	86.6	284.2	547.4	263.2	92.6
Mean				-11.0				39.3				151.4				151.9
Thinned, 4	631.2	493.2	-120.7	-19.7	592.3	531.3	-61.6	-10.4	499.8	373.8	-126.0	-25.2	493.5	590.8	97.3	19.7

[a] Values for logged plots are compared to those for undisturbed controls.

Measurements of soil temperature at a depth of 10 cm obtained in 1982 from undisturbed white spruce stands are in close agreement with measurements in similar stands on flood-plain sites. Viereck and others (1983) present values of 798 and 1140 (average 969) for soil degree-days measured at a depth of 10 cm in two mature white spruce stands on flood plains. Our comparable values for the 12 undisturbed plots on Willow Island ranged between 760 and 1177 with an average of 892.

The logging treatments were done during winter 1982-83. The soil-temperature measurements taken during summer 1983 indicated that tree removal and soil disturbance had apparently increased soil temperatures in some plots (figs. 2 and 3). The differences were, on the whole, rather small and inconsistent, and statistical analysis of values for soil degree-days at both the 10- and 20-cm depths showed differences between the control and treated plots to be nonsignificant (table 4). This result was somewhat surprising because we had expected that the logging treatments would be followed immediately by substantial increases in soil temperature. Indeed, these types of increases did occur at the 20-cm depth on the two clearcut and burned plots (table 3) but did not occur to the same extent on the other treated plots. We think the main reason for the slow temperature response was that the treatments were not completed until the end of the 1983 growing season: Burning on two of the clearcuts was not completed until the end of July, and scarification treatments on shelterwood units were not finished until fall 1983. Because these additional treatments would be expected to have considerable effect on soil temperatures, the delay in their implementation may explain the relatively small soil-temperature response during the first year.

Increases in soil temperature on treated plots were considerable during the second and third growing seasons (1984-85) after logging (tables 2 and 3 and figs. 2 and 3). In fact, in 1985 soil temperatures on the treated plots still seemed to be increasing relative to the control plots (fig. 3). Statistical analysis of soil degree-days at depths of 10 and 20 cm indicated that temperatures increased significantly ($P < 0.01$ at 10 cm and $P < 0.05$ at 20 cm) during both the 1984 and 1985 measurement periods (table 4). Temperature increases in 1985 at the 10-cm depth on logged plots vs. control plots averaged 20, 26, and 66 percent for shelterwood, clearcut, and clearcut and burned plots, respectively. The comparable figures for temperatures at 20 cm are considerably higher: 42, 70, and 163 percent for shelterwood, clearcut, and clearcut and burned plots, respectively (fig. 3).

Increases in soil temperature due to the logging treatments were actually greater at the 20-cm depth than they were at 10 cm. Temperature increases were also substantial at 50 cm, especially where shallow permafrost had existed before the logging treatments (fig 4). Heat conductivity is apparently efficient in these soils, which allows the rapid downward distribution of heat energy. The rapid conductivity may be partially the results of generally large amounts of soil moisture. Water, although it has a high specific heat, also has high thermal conductivity; thus moist soils conduct heat more efficiently than do dry soils. The effect of increased soil temperatures at depth on root development should be investigated. We can hypothesize that the volume of soil used effectively by plant roots substantially expands with increased soil temperatures such as we measured.

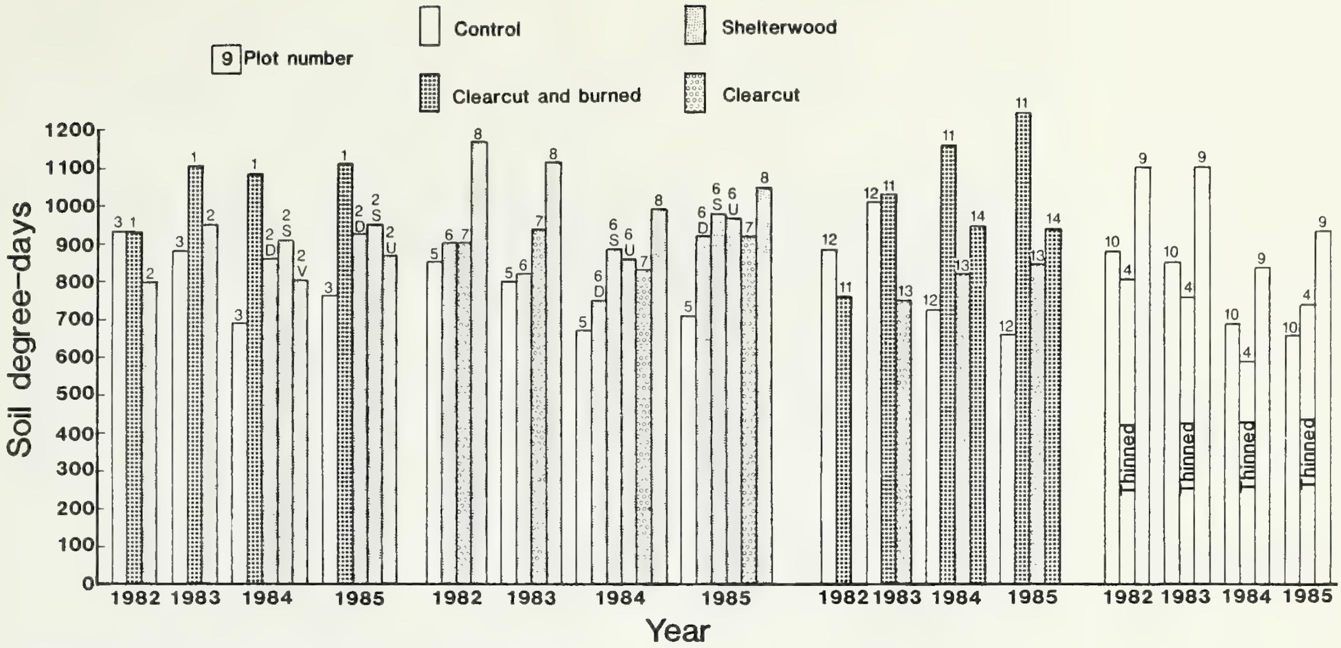

Figure 2—Soil degree-day values at a depth of 10 cm on the control, clearcut, shelterwood, and thinned plots before logging (1982) and the first 3 years after logging (1983-85).

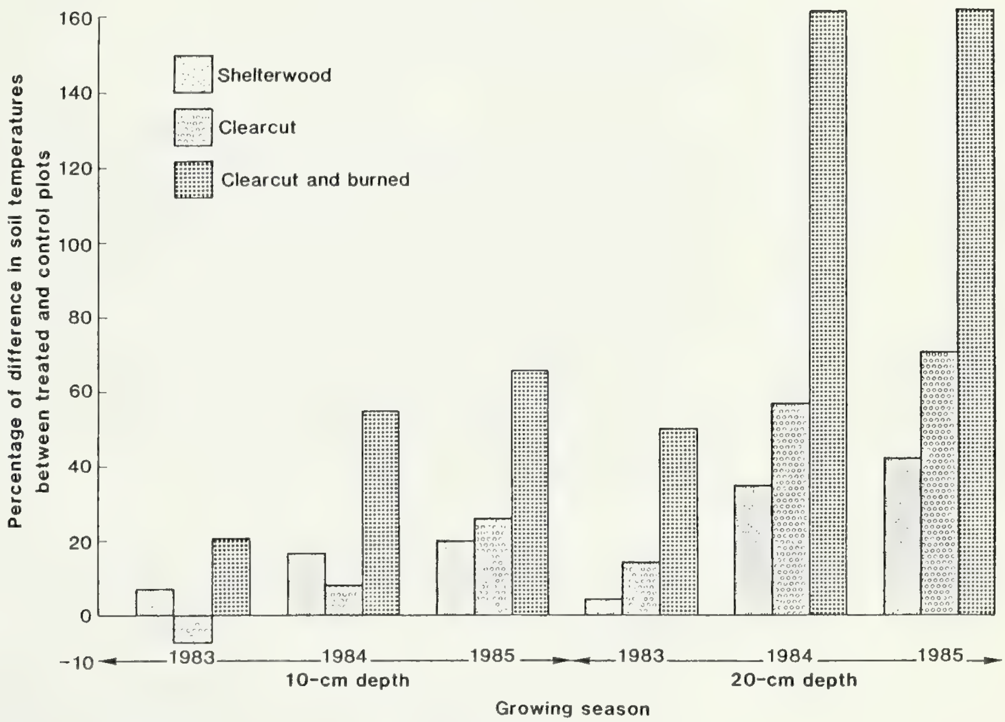

Figure 3—Differences in soil temperatures at depths of 10 and 20 cm from undisturbed controls at shelterwood, clearcut, and clearcut and burned locations.

Table 4—Means and standard errors of soil degree-day values at soil depths of 10 and 20 cm on the control and logged plots during summers in 1982 (before logging) and the first 3 years after logging (1983-85)[a]

Soil depth, treatment, and number of plots	Soil degree-days 1982	1983	1984	1985
At 10 cm:				
Control (n = 3)[b]	891.1 ± 24.6	895.6 ± 62.8a	701.6 ± 16.0a	712.6 ± 30.9a
Shelterwood (n=3)	960.1 ± 113.0	961.1 ± 85.7a	867.1 ± 66.9a	973.2 ± 40.9b
Clearcut (n=2)	908.6[c]	844.9 ± 92.4a	821.4 ± 5.2a	884.4 ± 31.1b
Clearcut and burned (n=3)	848.0 ± 87.8[d]	1,068.6 ± 38.1[d]a	1,064.2 ± 62.6b	1,099.9 ± 88.7c
At 20 cm:				
Control (n=3)	531.1 ± 58.1	533.2 ± 67.4a	393.4 ± 63.3a	451.0 ± 86.2a
Shelterwood (n=3)	632.3 ± 98.9	699.0 ± 121.4a	695.8 ± 83.5ab	859.3 ± 50.0b
Clearcut (n=2)	548.1[c]	575.8 ± 145.2a	567.0 ± 93.1ab	663.2 ± 141.1ab
Clearcut and burned (n=3)	501.6 ± 214.5[d]	724.5 ± 167.3[d]a	807.6 ± 155.6b	895.3 ± 173.9b

[a] Values followed by the same roman letter are not significantly different (P = 0.05).
[b] Temperature control plots 3, 5, and 12.
[c] Only 1 plot measured in 1982
[d] Only 2 plots measured in 1982 and 1983.

During late summer and fall 1983, blade scarification treatments were undertaken in the shelterwood areas. Areas 2-3 m in diameter were left where all organic materials were stripped off and bare mineral soil exposed. Intermixed with these scarified areas were areas where the forest floor had been disturbed and where the forest floor was undisturbed. Because we felt these conditions might be associated with different temperature regimes, soil temperatures were measured separately for each of the three shelterwood forest floor conditions in plots 2 and 6 during 1984 and 1985. As expected, soil temperature at 10- and 20-cm depths were consistently higher under scarified areas than they were under the other two conditions (tables 2 and 3). These differences were generally not large, and analysis of variance indicated they were not significantly different from values for the other shelterwood conditions. Perhaps the scarified areas were too small to exhibit the substantial temperature increases we expected.

The effect on soil temperature of slash burning plus clearcutting was dramatic: Increases in soil temperature were two to three times greater when clearcuts were slash burned than when they were not (tables 2 and 3, fig. 3). The average value for soil degree-days for 1985 at the 10-cm depth was 884 for clearcuttings and 1,199 for clearcuttings with burning. Comparable figures for the 20-cm depth were 663 for clearcuttings and 895 for clearcuttings with burning. The latter figure represents a sizable (2-1/2 times) increase over the soil degree-day value for the undisturbed control. Fires on both burned cutting units consumed logging slash almost completely and large portions of the forest floor. As a result, much of the organic insulating layer was removed, thus allowing the mineral soil to heat much more quickly. The blackened soil surface after the fires also undoubtedly contributed to increased soil temperatures because of more efficient absorption of the Sun's energy.

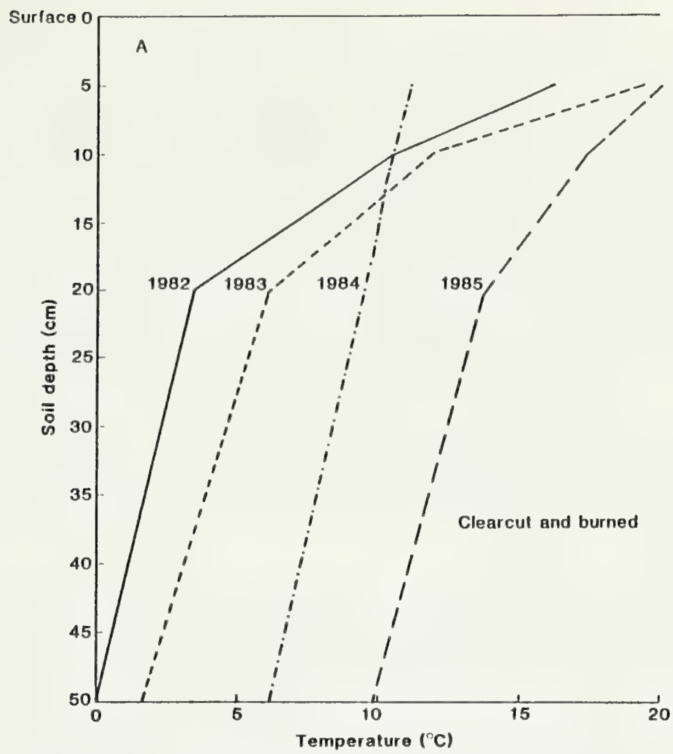

Figure 4—**A.** Soil temperature profile in mid-July at a clearcut and burned plot (11) before logging (1982) and the first 3 years after treatment (1983-85).

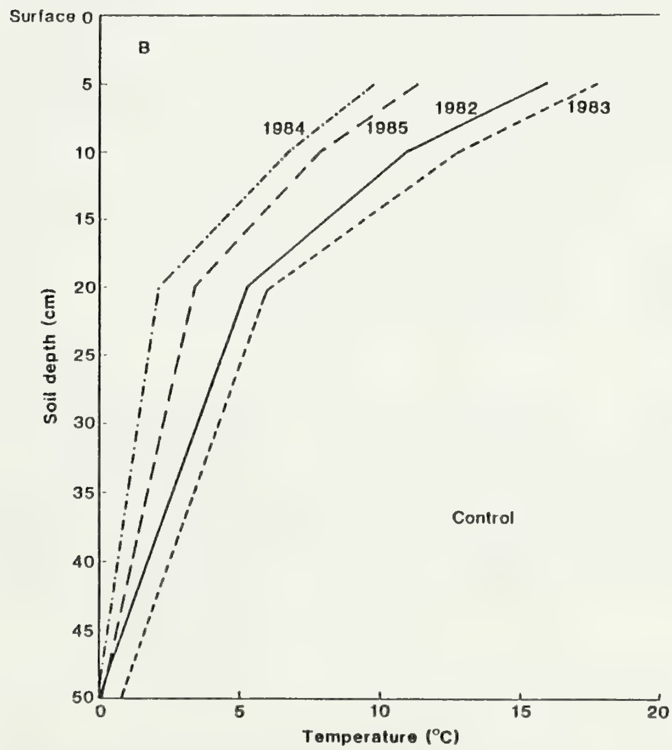

Figure 4—**B.** Soil temperature profile in mid-July on a paired, undisturbed control plot (12) for 1982-85.

The delayed response of soil temperature to the thinning treatment needs some explanation (tables 2 and 3). Actual thinning operations on the plot did not begin until winter 1983-84, when the trees to be removed were felled. The downed trees remained on the plot throughout the 1984 measurement period, and the slash provided additional insulation to the mineral soil. Because of this the soil temperatures for the treated plot for 1984 were slightly lower than those for the control plot. The felled trees were removed during winter 1984-85, so that only the final thinned stand remained on the plot during the 1985 growing season. Removing a substantial portion of the tree canopy apparently allowed more of the Sun's energy to reach the soil surface, as soil temperature warmed appreciably during 1985 (tables 2 and 3).

Year-to-year variations in soil temperatures were considerable. Although all four summers had cool, rainy periods, data from the control plots indicated that the summers of 1982 and 1983 produced noticeably warmer soil temperatures (tables 2 and 3, fig. 5). On most control plots, soil temperatures were coolest in 1984 and warmed somewhat in 1985.

Strong yearly variation was also evident in frost distribution within the measured soils (table 5). The data collected for frost during the four growing seasons strongly reinforced the view that many soils on Willow Island are on the margin of developing permafrost; these soils may have deep frost throughout the growing season if summer temperatures are cool, but not during the following summer if temperatures are higher. This is why many soils we sampled showed continuous frost in only two of the four sampling periods. The only plots to show consistent, fairly shallow permafrost were control plots 5 and 12. With gradually increasing forest floor thickness, and in the absence of logging, fire, or other radical disturbance, a progressive increase in the area of Willow Island underlain by soils containing permafrost is expected.

Probably the most spectacular change in soil-temperature regime occurred on plot 11 (clearcut and burned). Before treatment (1982), this site had a shallow permafrost table and soil temperatures that were actually substantially cooler than the nearby control (tables 2, 3, and 4). By the second summer after treatment (1984), all frost had left the profile and the soil degree-day value for the 20-cm depth was up to an astounding 938 vs. only 267 for the control. At the 10-cm depth, the soil degree-day value went from 760 (1982) to 1247 (1985). An increase in soil temperature of this magnitude indicates a substantial increase in potential site productivity. A soil degree-day value of 760 is typical of black spruce sites, and a value of 1247 is higher than the average values reported for the most highly productive balsam poplar and white spruce sites (Viereck and others 1983).

Effects of Logging Treatment on the Natural Vegetation

The initial responses of the vegetation to the five silvicultural treatments differed considerably among treatments, in part because of differences in the original vegetation types. What follows is a discussion of how logging treatment affected the survival of the prelogged vegetation and the development of the natural vegetation for the first 2-3 years after logging. Tables 6, 7, and 8 present information on pretreatment and control vegetation and the response to the silvicultural treatments for each community type. We will summarize the effects by silvicultural treatment regardless of original forest type.

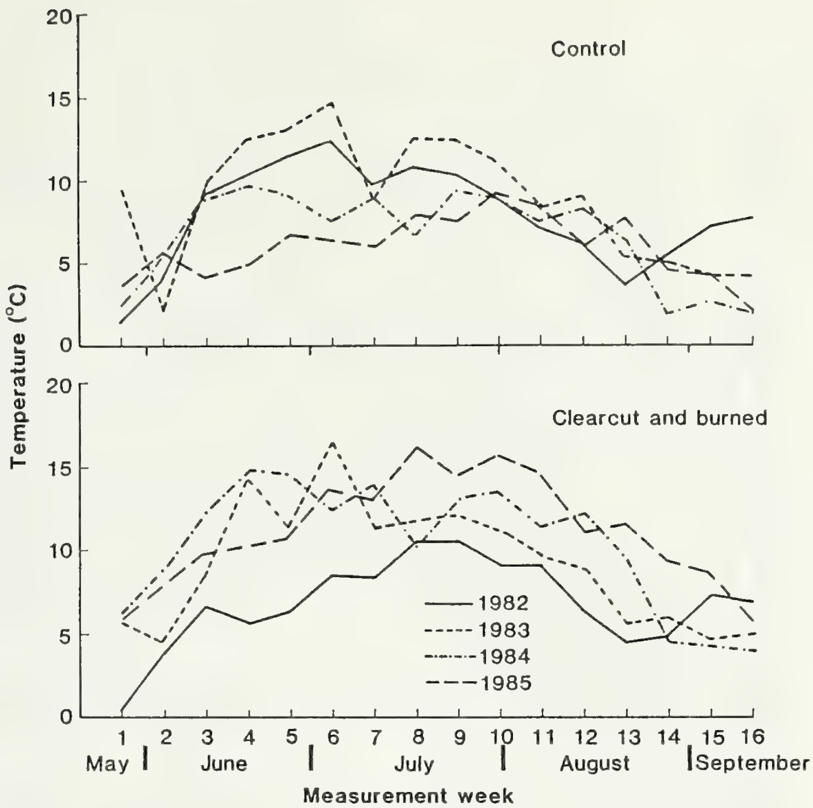

Figure 5—Summer soil temperatures at a depth of 10 cm on an undisturbed control plot (12) and a nearby clearcut and burned plot (11) for 1982-85.

Table 5—Maximum depth to frost at the end of the growing season (mid-September) in 1982 (before logging) and in the first 3 years after logging (1983-85) after logging on each of the soil-temperature plots[a]

Soil-temperature plot number	Treatment	Depth to frost 1982	1983	1984	1985
		Centimeters			
3	Control	No frost	168	128	No frost
1	Clearcut and burned	No frost	No frost	No frost	No frost
2	Shelterwood	No frost	No frost	No frost	No frost
5	Control	61	65	60	67
6	Shelterwood	No frost	68	147	No frost
7	Clearcut	No frost	186	No frost	No frost
8	Shelterwood	158	106	No frost	No frost
12	Control	69	83	74	82
11	Clearcut and burned	66	87	No frost	No frost
13	Clearcut		87	99	No frost
14	Clearcut and burned			87	112
9	Control	No frost	No frost	No frost	No frost
10	Control	No frost	No frost	No frost	No frost
4	Thinned	No frost	No frost	128	No frost

[a] Each value is based on 8 separate measurements of frost depth.

Table 6—Average percentage of cover and average percentage of frequency of the vegetation before and after 3 silvicultural treatments in the open *Picea glauca/Alnus crispa-A. tenuifolia/Vaccinium vitis-idaea/Hylocomium splendens* forest type, Willow Island

Plant species and category by layer	Control: Pretreatment, units 2-9		Treatment: Postclearcut, units 3, 6, 9 — Year 1		Year 2		Postshelterwood 14-m spacing, units 2, 7 — Year 1		Year 2		Postshelterwood 9-m spacing, units 4, 5, 8 — Year 1		Year 2	
	Cover	Frequency	Cover	Frequency	Cover	Frequency	Cover	Frequency	Cover	Frequency	Cover	Frequency	Cover	Frequency
	Percent													
Tree, sapling, and seedling canopy:	21.5	100	0.2	24	0.7	55	2.7	90	3.6	95	4.8	80	4.6	93
Betula papyrifera		83								38				33
Picea glauca		100						90		90		80		93
Picea mariana		1												
Populus balsamifera		7								50				27
Tree, sapling and seedling stem cover	1.4	58	.2	24	.6	55	1.9	85	1.7	95	.4	23	.8	72
Tree seedling canopy (only):	.6	38	.2	24	.7	55	1.1	90	2.3	95	.3	20	1.0	78
Betula papyrifera	.1	7	.1	7	.2	20	.3	23	.4	35	.1	5	.1	12
Picea glauca	.5	29	.2	20	.4	40	.8	78	.9	80	.2	15	.7	58
Populus balsamifera	[a]+	2			.2	8	.2	13	1.1	23	.1	5	.2	10
Populus tremuloides					.2	15			.1	5			+	2
Tall shrub canopy:	62.5	100	6.3	100	32.4	97	11.0	100	22.5	100	17.7	100	39.0	100
Alnus crispa	35.1	63	1.1	24	.9	19			1.6	15	2.2	13	5.0	28
Alnus tenuifolia	20.5	44	.3	14	1.3	15	5.0	70	6.2	58	6.6	52	7.5	47
Betula glandulosa					+	2								
Rosa acicularis	13.8	98	4.7	98	27.6	96	7.3	98	16.5	100	10.2	100	26.9	100
Rubus idaeus			.1	5	.1	6	.1	3	.1	3			.1	7
Salix alaxensis									.1	3				
Salix arbusculoides	.1	4	.1	8	.3	13	.1	3						
Salix bebbiana/glauca	+	3	+	2	.1	7	.2	15	.2	13				
Salix novae-angliae	.2	1	.3	6	.5	5			.1	3			.2	2
Salix species	+	1	+	4			.1	10	.1	8				
Viburnum edule	1.5	54	.4	35	.4	29	.6	55	.8	43	.4	32	.6	48

See footnote at end of table.

Table 6—Average percentage of cover and average percentage of frequency of the vegetation before and after 3 silvicultural treatments in the open *Picea glauca/Alnus crispa-A. tenuifolia/Vaccinium vitis-idaea/Hylocomium splendens* forest type, Willow Island (continued)

Plant species and category by layer	Control: Pretreatment, units 2-9		Treatment: Postclearcut, units 3, 6, 9				Postshelterwood 14-m spacing, units 2, 7				Postshelterwood 9-m spacing, units 4, 5, 8			
			Year 1		Year 2		Year 1		Year 2		Year 1		Year 2	
	Cover	Frequency	Cover	Frequency	Cover	Frequency	Cover	Frequency	Cover	Frequency	Cover	Frequency	Cover	Frequency
	Percent													
Low shrub canopy:	35.7	98	2.4	82	7.8	83	5.4	90	10.5	90	8.9	97	21.5	98
Empetrum nigrum	+	1					+	3	.1	3				
Ledum groenlandicum	.2	3	+	3	+	3	+	3			.1	3	.1	3
Linnaea borealis	13.4	92	.8	56	4.5	66	2.8	65	7.3	68	3.2	82	11.4	90
Potentilla fruticosa							+	3						
Ribes triste	.1	8	+	4	.1	13	.1	5	.1	8	.1	5	.2	15
Salix myrtillifolia	.2	1	+	2	.1	3					.2	2	.1	2
Vaccinium uliginosum	.3	6	+	2	.1	7	.2	5	+	3	.2	10	.5	13
Vaccinium vitis-idaea	24.9	86	1.9	60	3.6	68	2.9	60	3.2	53	6.7	92	11.4	93
Herb canopy:	42.6	100	9.9	98	43.3	97	14.1	100	49.8	100	9.8	98	37.3	98
Arctagrostis latifolia			+	2	1.3	20			3.5	20			.2	5
Astragalus alpinus			1.5	2	.7	3					.1	2	.1	2
Boschniakia rossica	+	1												
Calamagrostis canadensis	2.2	26	1.1	20	6.2	20	2.4	38	6.3	35	1.0	27	9.3	33
Carex disperma	0.2	3			.1	3								
Carex species	1.5	19	.2	14	.7	23	.1	8	.4	15	.1	5	1.9	25
Carex vaginata	.8	7					.1	8	.2	10	2.1	32	1.2	17
Cornus canadensis	10.2	81	3.4	75	12.3	80	3.6	83	8.9	85	3.6	70	9.1	72
Epilobium adenocaulon/hornemanni			+	2	.2	7							+	2
Epilobium angustifolium	+	1	+	2	.6	23	.2	15	1.6	28	.2	2	.6	12
Equisetum arvense	18.7	84	3.3	70	18.9	85	6.0	88	23.7	95	1.7	58	11.4	80
Equisetum scirpoides	9.0	53	.2	14	1.3	38	2.8	73	6.7	75	.7	28	2.6	42
Galium trifidum			+	2			.1	3	.3	8	+	2	.1	2
Geocaulon lividum	3.4	53	.3	27	.1	9	.1	13	.1	8	1.2	40	.9	30
Goodyera repens	.4	21												
Hedysarum alpinum	1.0	9	.7	11	1.9	10	.1	5	.7	8	.4	15	1.1	18
Iris setosa							.1	5	.2	5				
Lycopodium annotinum	.1	4	+	2	.1	3							.9	10

Table 6—Average percentage of cover and average percentage of frequency of the vegetation before and after 3 silvicultural treatments in the open *Picea glauca/Alnus crispa-A. tenuifolia/Vaccinium vitis-idaea/Hylocomium splendens* forest type, Willow Island (continued)

Plant species and category by layer	Control: Pretreatment, units 2-9		Treatment: Postclearcut, units 3, 6, 9 — Year 1		Postclearcut Year 2		Postshelterwood 14-m spacing, units 2, 7 — Year 1		Postshelterwood 14-m Year 2		Postshelterwood 9-m spacing, units 4, 5, 8 — Year 1		Postshelterwood 9-m Year 2	
	Cover	Frequency	Cover	Frequency	Cover	Frequency	Cover	Frequency	Cover	Frequency	Cover	Frequency	Cover	Frequency
	Percent													
Mertensia paniculata	.4	11	.2	19	1.6	27	.4	8	3.2	8	.1	10		
Moehringia lateriflora	+	4	+	2	+	2			+	3				
Moneses uniflora	.5	21									+	2	+	2
Platanthera obtusata	+	2											+	2
Poa species					4.7	18			.2	5	.2	8	2.2	18
Potentilla palustris							+	3	.3	3				
Pyrola asarifolia/chlorantha	4.6	45	.1	6	.2	7	.2	13	.5	13	1.0	47	2.2	53
Pyrola minor													.1	5
Pyrola secunda	1.2	36	.1	6	.1	13	.2	15	.4	20	.1	5	.4	25
Pyrola species					+	4			.1	13				
Rorippa islandica							.1	5	.3	5				
Rubus arcticus	.2	4	.1	7	.5	5	.2	8	.1	5				
Saussurea angustifolia	+	1	.1	3	.1	3					+	2	+	2
Stellaria longipes					.1	5	+	3	.2	13			+	3
Taraxacum species					+	2								
Trientalis europaea							+	3						
Unidentified Compositae									.1	5				
Unidentified Cruciferae									.1	3				
Unidentified Graminae	.7	9	.6	15			.1	3						
Unidentified herb									+	3				
Moss canopy:	65.6	99	.3	30	5.1	77	1.6	63	9.6	95	3.7	65	11.3	83
Aulacomnium palustre					.2	6			.2	5				
Brachythecium salebrosum									.6	18			+	2
Bryum species	.6	14			.8	17	.2	8	.2	18			.6	17
Ceratodon purpureus	.1	1												
Climacium dendroides													+	2
Dicranum species	1.1	32			.4	16			1.2	35	.1	7	.1	5
Distichum capillaceum					+	2								

Table 6—Average percentage of cover and average percentage of frequency of the vegetation before and after 3 silvicultural treatments in the open *Picea glauca/Alnus crispa-A. tenuifolia/Vaccinium vitis-idaea/Hylocomium splendens* forest type, Willow Island (continued)

	Control		Treatment											
	Pretreatment, units 2-9		Postclearcut, units 3, 6, 9				Postshelterwood 14-m spacing, units 2, 7				Postshelterwood 9-m spacing, units 4, 5, 8			
			Year 1		Year 2		Year 1		Year 2		Year 1		Year 2	
Plant species and category by layer	Cover	Frequency	Cover	Frequency	Cover	Frequency	Cover	Frequency	Cover	Frequency	Cover	Frequency	Cover	Frequency
	Percent													
Drepanocladus species	3.0	49			+	3	.1	5			.1	3	.2	15
Eurhynchium species	7.2	69			.7	26	.2	10	1.2	40	.4	17	.4	20
Homalothecium nitens	.2	3												
Hylocomium splendens	48.3	91	.2	19	.7	30	.3	20	4.1	45	2.9	65	9.9	78
Marchantia polymorpha					.4	11							+	2
Mnium species	.2	8												
Pleurozium schreberi	1.2	12	+	3	.4	3	+	3	.6	8	+	3	.1	2
Polytrichum species					.1	5								
Ptilidium ciliare							.1	3			+	2	.1	2
Ptilium crista-castrensis	.7	6					+	3	+	3	+	2	.1	3
Rhytidiadelphus triquetrus	5.6	22	+	4			.8	25	1.8	15	+	3	+	3
Rhytidium rugosum			.1	8							.5	2	.3	3
Unidentified leafy liverwort	1.9	29												
Unidentified moss	.7	9	.1	7	2.0	26	.4	23					.1	7
Lichen:	.5	19			+	2			+	3			.1	5
Cladonia gracilis	+	1											+	2
Cladonia species	.1	4			+	2			+	3			+	3
Peltigera aphthosa	.1	8												
Peltigera canina	.3	13												

[a] + means the value is less than 0.1 percent.

Table 7—Average percentage of cover and average percentage of frequency of the vegetation before and after 3 silvicultural treatments in the open *Picea glauca/Alnus tenuifolia/Hylocomium splendens* forest type, Willow Island

Plant species and category by layer	Control: Pretreatment, units 11-15		Treatment: Clearcut/burn, unit 12				Clearcut, units 13, 15				Shelterwood, 9-m spacing, units 11, 14			
			Year 1[a]		Year 2		Year 1		Year 2		Year 1		Year 2	
	Cover	Frequency	Cover	Frequency	Cover	Frequency	Cover	Frequency	Cover	Frequency	Cover	Frequency	Cover	Frequency
	Percent													
Tree, sapling and seedling canopy:	18.8	100	.7	55	.7	55	.3	48	.9	48	8.7	100	6.4	100
Betula papyrifera		29						48		48				
Picea glauca		100						40		40		100		100
Populus balsamifera		84								40				90
Tree, sapling and seedling stem cover	.7	33	.7	55	.6	55	.2	20	.3	28	.6	20	1.2	55
Tree seedling canopy only:	.4	23	.7	55	.7	55	.2	20	.3	28	.2	13	.7	58
Betula papyrifera							.1	3						
Picea glauca	.2	13	.4	40	.1	5	.2	13	.3	20	.2	10	.6	55
Picea species	.1	7			.2	15								
Populus balsamifera	[b]+	3	.1	5			.1	5	.1	8	.1	3	.2	3
Populus tremuloides			.4	40	.7	55								
Tall shrub canopy:	39.2	100	3.0	75	4.8	80	6.4	90	31.3	90	4.8	93	18.6	95
Alnus tenuifolia	28.3	73					1.6	40	5.0	40	1.6	43	4.8	50
Rosa acicularis	13.1	89	2.7	70	4.6	75	5.3	85	24.0	90	3.4	85	14.6	93
Rubus idaeus			.1	5	.1	5			.1	3			.1	3
Salix arbusculoides					.1	10								
Salix bebbiana/glauca					.3	25								
Salix novae-angliae											.1	3	.1	3
Salix species			.1	5	.2	20								
Viburnum edule	1.7	48	.2	20	.2	20	.4	25	2.6	28	.4	38	1.1	55
Low shrub canopy:	26.9	70	.1	5	.1	5	2.2	50	5.3	53	1.5	58	7.6	60
Arctostaphylos rubra	.9	4					.3	5	.1	5	+	3	.1	3
Linnaea borealis	23.3	68					1.9	43	5.0	43	1.5	58	7.4	60
Potentilla fruticosa											+	3	.1	3
Vaccinium vitis-idaea	4.4	9	.1	5	.1	5	.1	10	.2	10				

See footnote at end of table.

Table 7—Average percentage of cover and average percentage of frequency of the vegetation before and after 3 silvicultural treatments in the open *Picea glauca/Alnus tenuifolia/Hylocomium splendens* forest type, Willow Island (continued)

Plant species and category by layer	Control: Pretreatment, units 11-15		Treatment: Clearcut/burn, unit 12				Clearcut, units 13, 15				Shelterwood, 9-m spacing, units 11, 14			
			Year 1[a]		Year 2		Year 1		Year 2		Year 1		Year 2	
	Cover	Frequency	Cover	Frequency	Cover	Frequency	Cover	Frequency	Cover	Frequency	Cover	Frequency	Cover	Frequency
	Percent													
Herb canopy:	31.0	97	.6	20	3.4	50	5.6	90	21.9	90	6.2	90	18.3	93
Calamagrostis canadensis	.3	4					.2	10	1.8	13	.4	8	2.3	13
Capsella bursa-pastoris					.5	5								
Carex species	2.3	25	.1	5	.3	25	1.4	38	2.0	35	.3	10	.4	10
Carex vaginata											2.2	10	2.2	13
Cornus canadensis	.7	9					.6	15	.8	10	.3	15	.8	15
Elymus alaskanus	.1	2												
Epilobium angustifolium	.2	7	.5	10	2.3	30	.2	10	1.2	13	.1	3	1.6	13
Equisetum arvense	11.4	60			.4	5	1.6	50	7.9	70	2.2	43	7.3	63
Geocaulon lividum	10.8	74					.6	40	.2	15	.7	40	1.3	30
Goodyera repens	.4	14												
Hedysarum alpinum	2.1	22	.1	5	.1	5	1.1	33	2.3	28	.2	8	.8	10
Moehringia lateriflora	.5	10					.4	23	4.9	43	+	3	1.0	15
Moneses uniflora	.7	32					.1	8			.1	8		
Platanthera obtusata	.1	6									+	3	.1	3
Poa species							.1	5	.7	10	+	3	.2	3
Pyrola asarifolia/chlorantha	2.7	27					.1	10	.6	28	.1	8	.7	23
Pyrola secunda	2.7	58					+	3	.3	23	.4	30	.6	33
Pyrola species							.1	10			.3	18		
Rubus arcticus	.9	7					.3	8	1.5	10	.3	8	1.2	10
Stellaria longipes							.1	5	.3	5				
Trientalis europaea	.1	2					+	3	.1	3	+	3	.1	3
Unidentified Graminae	.1	4					.1	8	.5	8			.1	3
Moss canopy:	78.9	99	1.0	45	17.7	100	.5	40	1.7	80	5.0	85	33.9	95
Bryum species	.2	10							.1	10	+	3	.2	13
Ceratodon purpureus			.8	35	17.1	100								
Dicranum species	.8	34							.1	5	.1	8	.3	18
Drepanocladus species	2.9	53							+	3	+	3		

Table 7—Average percentage of cover and average percentage of frequency of the vegetation before and after 3 silvicultural treatments in the open *Picea glauca/Alnus tenuifolia/Hylocomium splendens* forest type, Willow Island (continued)

Plant species and category by layer	Control: Pretreatment, units 11-15		Treatment: Clearcut/burn, unit 12				Clearcut, units 13, 15				Shelterwood, 9-m spacing, units 11, 14			
			Year 1[a]		Year 2		Year 1		Year 2		Year 1		Year 2	
	Cover	Frequency	Cover	Frequency	Cover	Frequency	Cover	Frequency	Cover	Frequency	Cover	Frequency	Cover	Frequency
	Percent													
Eurhynchium species	5.5	68							.1	13	.5	10	.3	13
Hylocomium splendens	72.5	98					.5	40	1.3	68	4.2	83	33.3	90
Marchantia polymorpha			.3	10	1.0	45							.1	5
Mnium species	.1	10			.1	5								
Pleurozium schreberi	.3	6									.2	8		
Polytrichum species	.5	3					+	3			.3	5	.1	8
Ptilidium ciliare	.3	4									.1	5		
Ptilium crista-castrensis	.1	4												
Rhytidium rugosum	.1	4												
Unidentified leafy liverwort	.3	16												
Unidentified moss	.3	5	.1	10					.2	5	+	3	+	3
Lichen:	1.5	38					.1	10	.1	10	.1	10	.1	8
Cladonia gonecha									+	3				
Cladonia gracilis	+	4					+	3						
Cladonia species	.1	3					+	3					+	3
Peltigera aphthosa	.7	18					.1	10	.1	5	.1	5	.1	5
Peltigera canina	.7	27							+	3	.1	5		
Peltigera species									+	3				

[a] Treatment not complete until August 1983 so the first post growing season is 1984 or 1 year later than for the other treatments.
[b] + means the value is less than 0.1 percent.

Table 8—Average percentage of cover and percentage of frequency of the vegetation before and after 1 silvicultural treatment in the Woodland *Picea glauca/Ledum groenlandicum-Vaccinium vitis-idaea/ Hylocomium splendens* forest type, Willow Island

Plant species and category by layer	Control; pretreatment, unit 16		Treatment; postclearcut/burn, unit 16					
			Year 0		Year 1		Year 2	
	Cover	Frequency	Cover	Frequency	Cover	Frequency	Cover	Frequency
	Percent							
Tree, sapling and seedling canopy:	18.8	100	0	0	.8	75	1.0	95
Betula papyrifera		100						
Picea glauca		100						
Picea mariana		75						
Tree, sapling and seed stem cover	1.8	75			.8	75	1.0	95
Tree seedling canopy only:	2.0	30	0	0	.8	75	1.0	95
Betula papyrifera	.3	20					.6	55
Picea glauca	.2	10					.1	10
Picea mariana	1.8	20						
Populus balsamifera							.6	55
Populus tremuloides					.8	75	.9	90
Tall shrub canopy:	16.9	100	0	0	.1	10	.9	80
Alnus crispa	.5	5						
Rosa acicularis	11.4	95			.1	5	.1	10
Salix arbusculoides	.1	5			.1	5	.2	15
Salix bebbiana/glauca	6.8	55					.6	60
Salix novae-angliae							.6	65
Low shrub canopy:	80.1	100	0	0	0	0	0	0
Empetrum nigrum	9.5	20						
Ledum groenlandicum	31.8	65						
Linnaea borealis	5.3	60						
Vaccinium vitis-idaea	59.5	100						
Herb canopy:	31.3	100	0	0	54.0	100	71.6	100
Calamagrostis canadensis	2.5	75			.4	15	.9	15
Cornus canadensis	5.7	90						
Epilobium adenocaulon/hornemannii							.1	5
Epilobium angustifolium					1.4	60	1.2	75
Equisetum arvense	17.8	100			53.5	100	71.2	100
Equisetum scirpoides	.8	25						
Geocaulon lividum	8.4	95						
Lycopodium annotinum	.1	5						
Pyrola asarifolia/chlorantha	.2	20						
Pyrola secunda	.1	5						
Senecio species	.3	5						
Stellaria species	.1	5						
Taraxacum species							.1	5
Moss canopy:	65.4	100	0	0	26.4	100	56.6	100
Aulacomnium palustre	3.3	40						

Table 8—Average percentage of cover and percentage of frequency of the vegetation before and after 1 silvicultural treatment in the Woodland *Picea glauca/Ledum groenlandicum-Vaccinium vitis-idaea/Hylocomium splendens* forest type, Willow Island (continued)

Plant species and category by layer	Control Pretreatment, unit 16		Treatment postclearcut/burn, unit 16					
			Year 0		Year 1		Year 2	
	Cover	Frequency	Cover	Frequency	Cover	Frequency	Cover	Frequency
	Percent							
Bryum species	1.5	25						
Ceratodon purpureus	.1	10			11.4	95	35.7	100
Dicranum species	8.1	50						
Drepanocladus species	1.8	60						
Hylocomium splendens	37.4	95						
Hypnum species	.1	10						
Marchantia polymorpha					18.9	95	26.7	90
Pleurozium schreberi	21.6	80						
Polytrichum species	.7	15						
Ptilidium ciliare	3.5	40						
Unidentified leafy liverwort	.1	10						
Lichen:	30.1	100	0	0	0	0	0	0
Cladonia amaurocraea	.6	30						
Cladonia gracilis	1.7	50						
Cladonia rangiferina	2.1	40						
Cladonia sylvatica	.6	25						
Cladonia species	.7	45						
Nephroma arcticum	.1	5						
Peltigera aphthosa	23.4	85						
Peltigera canina	2.7	70						

Clearcutting followed by burning--Clearcutting followed by slash burning caused the greatest disturbance to the site and vegetation. Considerable differences in effects were observed in the two burned units because of differences in the original vegetation and the intensity of the fire. In unit 12, 99 percent of the surface was classified as charred material, ash, or mineral soil; over 60 percent of the surface was covered with ash, and 10 percent of the surface was burned to mineral soil (table 9 and fig. 6). A year later, when the ash had been concentrated, washed, or blown away, 41 percent of the surface was classified as mineral soil. In unit 16, which had a thicker preburn organic layer, 75 percent was classified as ash but only 6 percent as mineral soil immediately after the fire. A year later, the exposed mineral soil had increased to 30 percent.

At units 12 and 16, the fire was severe enough to kill the biomass above and below the ground of most species, including the alder shrubs. Of the species found on these two sites before treatment, 31 were killed and had not reinvaded after two posttreatment growing seasons. The tabulation shows the species that were on the sites before treatment but were removed by the treatment (tables 7 and 8):

Units 12 and 16
Linnaea borealis[2]
Vaccinium vitis-idaea[2]
Equisetum scirpoides[3]
Moneses uniflora
Pyrola spp.

Unit 12
Alnus tenuifolia[2]
Calypso bulbosa (L.) Rehb.
Fragaria virginiana Duschesne
Goodyera repens
Platanthera obtusata (Pursh) Lindl.
Rubus arcticus L.
Stellaria longipes Goldie

As expected, the mosses and lichens of the mature forest were also eliminated by the fire.

The clearcut and burned sites, on the other hand, provided excellent seedbeds for invading seeds and other propagules. *Picea glauca, Populus balsamifera, P. tremuloides, Salix* spp., *Rubus idaeus* L., *Capsella bursa-pastoris* (L.) Medic., *Taraxacum* sp., *Ceratodon purpureus* (Hedw.) Brid., and *Marchantia polymorpha* L. have invaded one or more of these sites. *Equisetum arvense* surpassed its pretreatment cover values and dominated the site along with *Marchantia* and *Ceratodon.* Only two other species, *Rosa acicularis,* which sprouted from underground rhizomes, and *Epilobium angustifolium,* which invaded by wind-dispersed seeds, appeared with any significant cover on the clearcut and burned sites.

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[2] Pretreatment cover values of 5 or more percent.
[3] Pretreatment cover values of 2-4 percent.

Table 9--Average percentage of cover and average percentage of frequency of litter, logging debris, and other forest floor categories before and after silvicultural treatment, Willow Island[a]

Forest floor category by group	Control: Pretreatment, units 2-9 and 11-16		Treatment: Clearcut/burn, unit 12, 16						Treatment: Clearcut, units 3, 6, 9, 13, 15				Treatment: Shelterwood 14-m spacing, units 2, 7				Treatment: Shelterwood 9-m spacing, units 4, 5, 8, 11, 14			
			Year 0		Year 1		Year 2		Year 1		Year 2		Year 1		Year 2		Year 1		Year 2	
	Cover	Frequency	Cover	Frequency	Cover	Frequency	Cover	Frequency	Cover	Frequency	Cover	Frequency	Cover	Frequency	Cover	Frequency	Cover	Frequency	Cover	Frequency
	Percent																			
Dead moss (initial posttreatment)									17.5	91			16.9	90			31.0	99		
Dead moss (end of season)									13.6	83			15.8	90			25.8	89		
Litter (initial posttreatment)			0.3	5					13.3	62			19.9	70			32.8	91		
Litter (end of season)	54.0	100	.4	10	0.1	3	20.0	100	66.8	100	49.1	97	71.4	100	43.0	100	62.2	99	29.6	98
Charred material (initial posttreatment):			99.0	100																
Ash cover			70.8	100																
Moderate burn severity			25.2	98																
Low burn severity			2.3	63																
Scorched			.2	10																
Charred material (end of season)			99.0	100	10.8	43	26.3	100			1.7	3								
Dead wood (initial posttreatment)			3.6	43																
Compressed logging debris (posttreatment):									67.8	100			57.2	98			51.0	99		
Litter and small diameter									48.2	100			45.7	98			42.9	99		
Medium diameter									11.6	61			8.4	40			5.4	39		
Large diameter									8.0	42			2.9	18			.2	20		
Loose debris (initial posttreatment)									38.7	100			43.7	100			42.5	100		
Dense debris (initial posttreatment)			2.3	28					7.2	80			11.0	90			7.6	72		
Dead snags (initial posttreatment)			1.9	73					1.4	30			1.1	23			.7	21		
Dead wood (end of season)	17.8	100	5.7	95	14.0	100	16.0	100	64.4	100	77.0	100	89.5	100	72.3	100	53.9	99	75.7	100
Mineral soil (initial posttreatment)			8.0	90					2.8	38			.9	30			.8	35		
Mineral soil (end of season)			8.0	90	35.4	93	15.3	98	.6	10	4.0	18	.2	10	.1	5	.1	1		
Organic soil (initial posttreatment)			.1	3					2.8	39			.3	18			.8	33		
Organic soil (end of season)					38.7	100	25.3	90	2.5	19	15.5	85	1.0	10	1.3	78	.2	7	2.3	51
Standing water									.1	1										

[a] Data is combined for all three forest types in which silvicultural treatments were made.

Figure 6—**A.** Open white spruce/thinleaf alder/feathermoss type (unit 12) before logging.

Figure 6—**B.** The same unit in June 1984 showing the results of clearcutting followed by burning in July 1983.

Figure 6—**C.** The same stand in 1985, 2 years after the silvicultural treatment, showing the slow recovery of the vegetation.

Figure 6—**D.** A 1-m^2 plot in unit 12 in 1984 showing charred logs and forest floor.

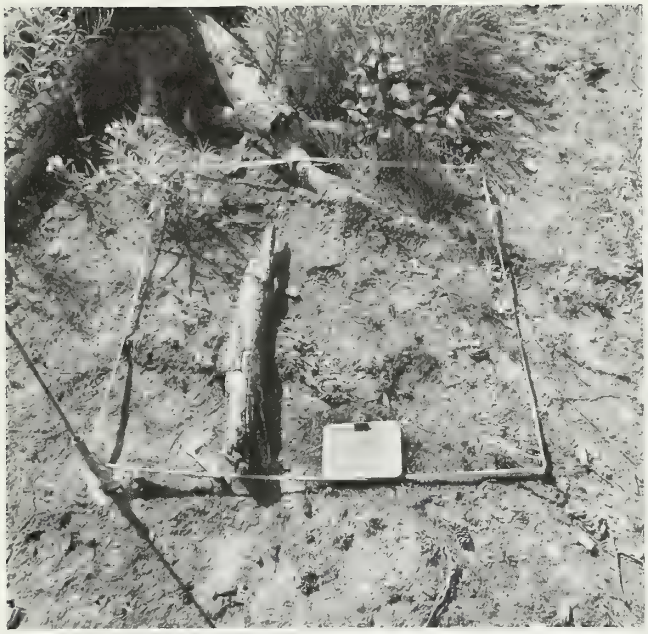

Figure 6—**E.** The same 1-m2 plot (but from a different angle) in 1985 showing condition of the forest floor and development of the vegetation.

Two years after the logging and burning, it appears that the sites may eventually be dominated by a mixed hardwood stand of upland and flood-plain species. Of special significance is the invasion of the burned sites by large numbers of aspen seedlings. Although aspen seedlings are occasionally found on newly established silt bars in the Tanana River, aspen seldom, if ever, persist to maturity. The first 3 years after logging were poor years for spruce seed on Willow Island, and thus the result has been low numbers of spruce seedlings in the burned clearcut units. Spruce seedlings occur but are outnumbered by *Populus tremuloides, P. balsamifera,* and *Betula papyrifera,* which are faster growing species. Neither *Alnus* species shows signs of vegetative recovery, and no *Alnus* seedlings have been found. The low shrubs, *Vaccinium vitis-idaea, Ledum groenlandicum,* and the feathermosses, *Hylocomium splendens* and *Pleurozium schreberi*, have been replaced by *Salix* spp., *Rosa acicularis, Calamagrostis canadensis, Equisetum arvense,* and the invading *Ceratadon purpureus* and *Marchantia polymorpha.*

Clearcut sites (unburned)--Clearcutting caused more disturbance of the vegetation and forest floor than did either of the shelterwood treatments but less disturbance than clearcutting with slash burning. Logging debris, consisting primarily of large- and small-diameter logs, branches, and needles, covered about 75 percent of the surface in the spring after the harvest. Much of the debris was compacted to several centimeters in depth, creating a poor seedbed for invading species; this may have accounted for the slow temperature response described in the section on soil temperature. Some mineral soil was exposed, especially at the landings and along skid trails, but the total was usually less than 10 percent (table 9 and fig. 7). Unlike the burned units, the unburned clearcuttings contained the live underground roots and rhizomes of many species, which allowed the plants to recover rapidly after the disturbance. Abundant basal sprouting from root crowns and undamaged lower stems also occurred. Although the feathermosses were not totally destroyed by the logging, the exposure to sunlight and drying during the summer after the logging effectively eliminated them from the units.

Figure 7—**A.** Open white spruce/thinleaf alder/feathermoss type (unit 13) before clearcutting.

Figure 7—**B.** The same location in June 1983, the first summer after clearcutting.

Figure 7—**C.** The same unit in 1985 showing a shrub canopy of *Alnus tenuifolia* and *Rosa acicularis*.

Figure 7—**D.** Typical logging debris in the same stand in June 1983, the first summer after clearcutting.

Of the 50 vascular species recorded in the plots before logging, only four—*Boschniakia rossica* (Cham. & Schlect.) Fedtsch., *Goodyera repens, Moneses uniflora,* and *Platanthera obtusata* (Pursh) Lindl.—were absent after the logging. In 1984, cover of *Arctostaphylos rubra* (Rehd. & Wilson) Fern., *Geocaulon lividum,* and *Viburnum edule* was still decreasing. Total live moss cover was drastically reduced, but of the 20 species recorded in the plots before logging, only 5—*Mnium* sp., *Polytrichum* sp., *Ptilium crista-castrensis* (Hedw.) De Not., *Rhytidiadelphis triquetrus*, and *Rhytidium rugosum* (Hedw.) Kindb.—were eliminated from all sites. Mosses eliminated from some but not all sites were *Dicranum* sp., *Drepanocladus* sp., and *Tomenthypnum nitens* (Hedw.) Loeske. The lichens were also eliminated or greatly reduced in all clearcut units (table 7).

Some species not recorded in the pretreatment plots were found in the plots after logging; these included *Rubus idaeus, Populus balsamifera, Epilobium adenocaulon* Hausk., *E. angustifolium, Stellaria longipes, Taraxacum* sp., and the nonvascular species, *Marchantia polymorpha* and *Aulacomnium palustre* (Hedw.) Schwaegr. Most of these species are the same as those invading the clearcut and burned sites.

Most of the surviving species developed rapidly once the canopy was removed. *Rosa acicularis* and *Calamagrostis canadensis* increased greatly in cover on all clearcut sites; and *Cornus canadensis, Equisetum arvense, Hedysarum alpinum, Mertensia paniculata,* and *Moehringia lateriflora* (L.) Frenzl increased in cover on some clearcut sites. After an initial decrease in 1983, the remaining species showed an increase in 1984.

Although cover values of most species had not reached pretreatment levels 2 years after logging, most were increasing rapidly and some, such as *Rosa acicularis* and *Calamagrostis canadensis*, had reached frequency and cover levels equal to or higher than those recorded before logging. In 1984, the leading dominants were *Rosa acicularis* (18-30 percent) for tall shrubs, *Linnaea borealis* (2-7 percent) for low shrubs, *Equisetum arvense* (4-35 percent) for herbs, and *Hylocomium splendens* (1-2 percent) for mosses. *Alnus tenuifolia, Vaccinium vitis-idaea, Calamagrostis canadensis, Cornus canadensis, Poa* sp., *Hedysarum alpinum,* and *Mertensia paniculata* attained cover values of at least 4 percent on some sites, however.

Most species characteristic of the pretreatment sites were present two years after clearcutting. Spruce seedlings were outnumbered by *Populus balsamifera* and *Betula papyrifera,* however. *Rosa acicularis* replaced *Alnus tenuifolia* and *A. crispa* as the dominant tall shrub. *Linnaea borealis* was more important in the low shrub layer than was *Vaccinium vitis-idaea. Hylocomium splendens,* with an original cover of 15-56 percent, survived in the logged stand, but the cover was reduced to an average of 2 percent.

Shelterwood; 14-m residual tree spacing--Disturbance of the vegetation and forest floor was less in the most open shelterwood treatments than in the clearcuts. The quantity and cover of logging debris was less, and pockets of relatively undisturbed vegetation surrounded some of the residual trees (table 9 and fig. 8). Mineral soil was only occasionally exposed, and only 1-2 percent cover of mineral soil was recorded in the plots in early summer 1983. More of the aboveground stems of the tall shrubs, especially alder, remained intact in the shelterwood plots than in the clearcut treatments. The cover of surviving tall shrubs was 9-13 percent in the 14-m residual tree spacing shelterwood compared to 6 percent in the clearcuttings. The shade created by the residual trees seems to have resulted in better survival of the original vegetation, especially the feathermosses, which had recovered in some areas to 11 percent cover by 1984.

Figure 8—**A.** Open white spruce/mixed alder/lingonberry/feathermoss type (unit 7) before logging.

Figure 8—**B.** The same location in June 1983, the first summer after a shelterwood treatment at a 14-m spacing.

Figure 8—**C.** Typical logging debris in June 1983, the first summer after the shelterwood treatment.

Species not reestablished after 2 years were *Ledum groenlandicum, Geocaulon lividum, Goodyera repens*, *Moneses uniflora,* and several mosses and lichens. Species invading some of the sites after logging included *Rubus idaeus, Epilobium angustifolium, Galium trifidum* L., *Iris setosa, Potentilla palustris* (L.) Scop., *Rorippa islandica* (Oeder) Barb., *Stellaria longipes*, and *Arctagrostis latifolia* (R.Br.) Griseb. Two years after logging, the dominant tall shrub species was *Rosa acicularis* (15-18 percent cover) although *Alnus tenuifolia* and to a lesser extent *A. crispa* were present and increasing in cover. *Linnaea borealis* and *Vaccinium vitis-idaea* dominated the low shrub layer, and *L. borealis* regained its pretreatment cover levels. The cover of *V. vitis-idaea* decreased initially but remained constant between 1983 and 1984 (tables 6 and 7).

In 1984, the dominant herbs in one or more of the units were *Cornus canadensis, Equisetum arvense, Calamagrostis canadensis, Arctagrostis latifolia, Mertensia paniculata,* and *Equisetum scirpoides* with total herb cover of up to 51 percent in some units. *Hylocomium splendens* was the dominant moss but occurred at only 3-5 percent cover, much lower than its pretreatment values (15-56 percent).

Although natural seedlings of *Picea glauca* were present, they were outnumbered and overtopped by *Populus balsamifera* seedlings.

Shelterwood; 9-m residual tree spacing--This denser shelterwood treatment resulted in the least disturbance of all the treatments in both open spruce community types (tables 6, 7, 9; fig. 9). The logging debris covered only 50 percent of the plots, whereas dead moss covered 31 percent, indicating much less physical disturbance of the forest floor. Surviving live mosses, primarily the original feathermoss, *Hylocomium*

splendens, retained an average cover of 3 percent and was able to expand rapidly in the first year, probably because of the shading effect of the residual trees. The tall shrub layer, especially alders and roses, remained partially intact.

Figure 9—**A.** Open white spruce/thinleaf alder/feathermoss type (unit 14) before logging.

Figure 9—**B.** The same location in June 1983, the first summer after a shelterwood treatment at a 9-m spacing.

Figure 9—C. A 1-m^2 plot before logging in unit 14.

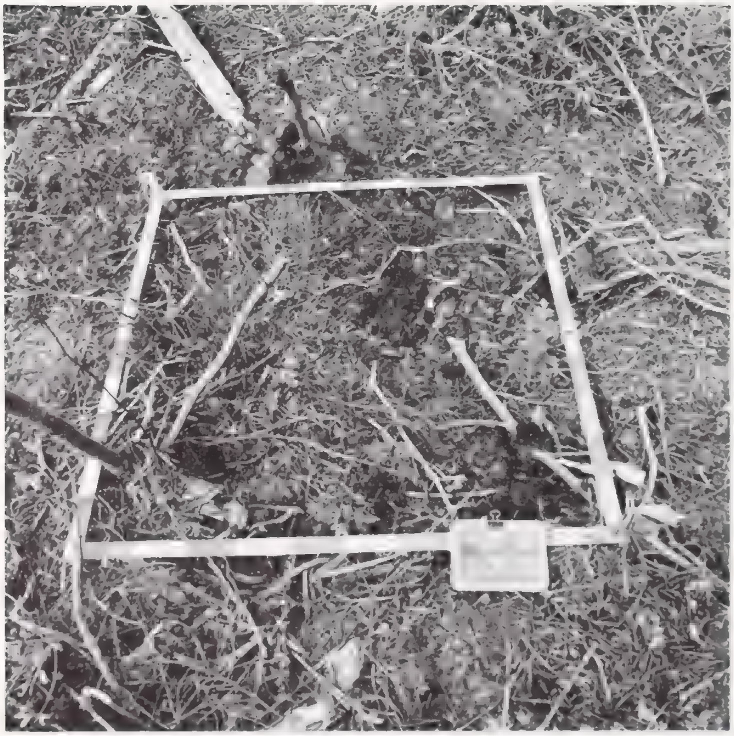

Figure 9—D. The same 1-m^2 plot in June 1983, the first summer after the shelterwood treatment.

Recovery of shrubs, herbs, and mosses during the two summers after logging was most rapid in the units with the 9-m residual tree spacing shelterwood treatment. *Rosa acicularis, Calamagrostis canadensis*, and *Cornus canadensis* had equaled or doubled their pretreatment cover values; *Alnus crispa, A. tenuifolia, Linnaea borealis, Vaccinium vitis-idaea, Equisetum arvense, Mertensia paniculata, Pyrola asarifolia,* and *Hylocomium splendens* made substantial increases toward regaining their pretreatment values. Many of the latter species have cover values of nearly half of their former levels.

Enough disturbance occurred to the sites to eliminate some species such as *Boschniakia rossica, Elymus alaskanus* (Scriebn. & Merr.) A. Löve, and *Goodyera repens,* and to greatly reduce others, such as *Moneses uniflora, Platanthera obtusata,* and many moss species. Some sites were available for invasion by new species: *Populus balsamifera, P. tremuloides, Rubus idaeus, Salix novae-angliae, Epilobium angustifolium, E. hornemannii* Rehbn., *Galium trifidum, Poa* sp., *Stellaria longipes,* and *Marchantia polymorpha* were found in the plots in 1984 but had not been present before logging.

The 9-m spacing shelterwood treatment had less impact on vegetation than did the other treatments. Species dominant before the treatment remained among the important species 2 years after logging.

Thinning plots--In addition to the two shelterwood treatments, a series of thinning plots was established in a dense, closed stand of white spruce (fig. 1, units A-L). The effects of the treatment were essentially the same as those for the 9-m spacing shelterwood so are not given in detail here or in the tables.

Conclusions

Forests on the flood plain of many Alaska rivers are the result of primary succession; that is, plant communities develop on sites not previously supporting vegetation. Logging on these sites results in subsequent changes in the forest community best described as secondary succession. One important aspect of our research was to learn more about the differences and similarities in forest development between primary and secondary succession on these sites. A remarkable feature of secondary succession is the invasion of aspen after harvesting and site preparation. Aspen is common on many of the units, especially the clearcut and burned sites. The species occurs only rarely in primary succession on these sites and then only in the seedling stage. The seed source for aspen is upland sites several kilometers from Willow Island. Following the fate of aspen on these sites will be especially interesting.

A decline in the site quality of white spruce stands occurs as these stands mature (Viereck 1970). This appears to be true for Willow Island, where dominant trees on older parts of the island exhibited markedly different height-growth patterns from those of young stands (Zasada 1984). The significant factor in this decline appeared to be closely related to a decrease in soil temperature as white spruce stands mature and the forest floor increases in thickness and insulating properties. Forest harvesting and site preparation have caused a significant increase in soil temperature, at least in the short term.

On Willow Island, Salchaket soils are warmest. The intermittent-frost phase of the Salchaket is intermediate in temperature; the Tanana soils, with continuous permafrost, are coldest.

In the subarctic, soil temperatures are important in controlling the distribution and productivity of forest communities. In summing up the results of their 5-year, interdisciplinary study, Van Cleve and Dyrness (1983) stated:

> Results of the research program indicate that taiga forest ecosystem structure and function largely are mediated by forest floor and mineral soil temperature. Black spruce, the forest type which displays lowest productivity and rates of nutrient cycling, occupies sites with the coldest soils. The most productive forest types, those which display most rapid nutrient cycling, are encountered on warmer soils.

An important consideration in any forest management strategy in interior Alaska is the impact on soil temperatures. Practices that increase soil warming may considerably increase the productive capacity of the site. In this study, we were able to assess the effects of clearcutting and the shelterwood silvicultural systems in white spruce stands on understory vegetation and soil temperatures. Not surprisingly, clearcutting followed by broadcast slash burning resulted in the most marked changes in vegetation and soil temperature. The slash fires burned under fairly dry conditions and consumed almost all available fuels. Many plant species present before disturbance were absent for the first 3 years after treatment. Inventories of permanent plots showed that 17 plant species were eliminated by logging and burning. The postdisturbance vegetation was sparse and dominated by invading species, such as *Ceratodon purpureus* and *Epilobium angustifolium,* and deep-rooted species, such as *Equisetum arvense* and *Rosa acicularis.* Seedbeds resulting from this treatment favored the germination of deciduous tree species; *Populus tremuloides, P. balsamifera*, and *Betula papyrifera* seedlings were common.

Removal of the vegetation and blackening of the soil surface by logging and burning resulted in spectacular increases in soil temperature. In the most outstanding case, soil temperatures were almost twice as high in the treated areas as they were in a nearby undisturbed control (as evaluated by soil degree-day values measured at a depth of 10 cm). As a result of this substantial soil warming, permafrost present before disturbance was gone from the soil profile by the second year after logging. The soil warming measured on this plot (which caused the plot to be almost three times as warm as the control at the 20-cm depth) is probably the maximum that could be expected as a result of a logging treatment.

Clearcutting without slash burning had less impact on the soil and vegetation. Although the trees were removed, many of the species in the understory remained in the stand after logging. We expect, however, that these residual species will be dominated over time by faster growing, more light-tolerant plants. Tree seedlings germinating and surviving on bare mineral soil were mostly *Populus balsamifera* and *Betula papyrifera.* Only a few white spruce seedlings were present.

Because of the remaining forest floor insulation and vegetative cover on clearcut sites, soil temperature increases were less than one-half those measured in areas clearcut and burned. The average increase in soil temperature in clearcuttings as compared to the undisturbed controls was 29 percent at a depth of 10 cm and 73 percent at 20 cm. Although these increases are smaller than with burning, they are still significant and suggest some substantial increases in site productivity.

The effects of the shelterwood treatments on the vegetation were minimal. Apparently removing some of the trees from a winter snowpack, combined with leaving partial overstory shade, results in preserving the characteristics of most of the preexisting vegetation. The only species present before disturbance, but absent after logging, were delicate, shade-loving herbs such as *Goodyera repens, Calypso bulbosa*, and *Cypripedium passerinum* Richards. The dominant prelogging species remained and, at the end of the third year after logging, were beginning to expand their coverage. White spruce seedlings were more abundant in the shelterwoods than in the clearcuts; those that survived logging appeared to be thriving.

Increases in soil temperature caused by shelterwood harvesting were somewhat less than those resulting from clearcutting. The differences were not great though. At the end of the third growing season after logging, soil temperatures had increased 58 percent at the 20-cm depth in shelterwoods vs. 73 percent in clearcuts. Despite some residual overstory shade, disturbance from creating shelterwoods is apparently sufficient for substantial soil warming.

The thinning treatment appeared to have the least impact on vegetation and soils, as we had expected. For the most part, no major vegetative changes were encountered. Unfortunately, the felled trees were left lying on some plots for several months, thereby allowing the buildup of a spruce beetle (Coleoptera: Scolytidae) population. The beetles attacked the residual trees, and tree mortality is expected to cause additional, serious site changes in the future. The thinning operation apparently did cause a small increase in soil temperatures. Figures for 1985 showed a 12-percent increase at the 10-cm depth and a 20-percent increase at 20 cm. These figures represent only a small sample, however, with only one thinned plot studied.

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During winter 1982-83, five silvicultural treatments were applied on Willow Island (near Fairbanks, Alaska): two types of shelterwood cuttings, a clearcutting, a clearcutting with broadcast slash burning, and a thinning. The effects of these treatments on vegetation, soil temperature, and frost depth were followed from 1983 through 1985. In 1984 and 1985, logged plots had significantly higher soil temperatures than did the controls; clearcut and burned sites had the greatest increases. Vegetation composition was profoundly changed on the clearcut and burned units and altered to a lesser extent on the units receiving the other treatments.

Keywords: Alaska, succession, forest communities, site preparation, soil series.

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